PAST, PRESENT, AND FUTURE IMPACTS OF CONSUMER-DRIVEN DEMAND ON MARINE SPECIES

A Thesis

by

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ABSTRACT

The National Marine Fisheries Services (NMFS) began compiling commercial catch statistics and their respective wholesale values in 1950; however, scientists and mangers know many fish species were heavily impacted prior to this date. Research on historical fishery exploitations is limited; even more limited is scientific research that observes the role of consumers in fishery trends. Consumer-driven demand is notably one of the most important components of commercial fisheries because this drives targeted-harvests. Within this thesis we observe the past (19th century), present (20th century), and future (21st century) of consumer-driven impacts on marine species.

Commercial extinction of Diamondback terrapin in Chesapeake Bay (1850-1930) is reconstructed using historical wholesale newspaper articles and periodicals, as well as, archived menus. This study presents the first and most comprehensive price-level assessment of a previously viable resource from Chesapeake Bay. Diamondback terrapin experienced the greatest changes in inflation-adjusted prices of any marine species, sustaining a 5.5-6% increase above the inflation rate over approximately 20 years for retail and wholesale markets, respectively.

Depletion of commercially valuable species (1890-2016) of the US West Coast were evaluated by comparing menu retail prices and wholesale NMFS data, virtually extending the government dataset back to 1900. We focused primarily on the years from 1950-1975

as these likely represented wild-caught species featured on menus. This study provided the first ecosystem-level price assessment and the first trophic-level assessment using fishery retail prices to demonstrate ‘Eating down the food web’. The data does not clearly show a ‘shifting baseline’ scenario for the Pacific Coast through these analyses; however, it may suggest it is more complex for consumer preference vs. fishing effort (previously studied). This study shows the need for more detailed analyses for fishery prices prior to 1950, as most of the species prices rise faster than the inflation-rate before this time.

Finally, the notion of consumer-driven demand was used to develop the first pilot-fishery model to be used to control the invasive Indo-Pacific lionfish in Aruba. Integral data inputs were identified for the initial model, as well as, a series of oral-surveys performed (n=117) with fishermen, divers, restaurant owners, government officials, and tourists to determine the public awareness and concern with lionfish. This was used to assess the likelihood of establishing a lionfish fishery through consumer demand. It was determined that Aruba could conceivably sustain ten dedicated lionfish divers.

Each of the studies are stand-alone, but collectively justify using consumer-driven demand as a means to evaluate fisheries. Scientists and fisheries managers are showing interest in the transition from single-species stock assessments to a more robust ecosystem-fisheries management approach. We suggest, through the results of these studies, that the role of consumers be evaluated and incorporated into these ecosystem-based fisheries management assessments.

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I would like to thank my committee chair, Dr. Jones, and my committee members, Dr. Rowe and Dr. Mileski, for their guidance and support throughout the course of this research. They provided overwhelmingly beneficial criticism and have helped to solidify my project.

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NOMENCLATURE

$/dish	Price per dish
$/dozen	Price per dozen
$/each	Price per each
$/kg	Price per kilogram
$/lb	Price per pound
$/oyster	Price per oyster
$/terrapin	Price per terrapin
$/unit	Price per unit
AAS	American Antiquarian Society
APS	American Periodical Series
CIA	Culinary Institute of America
CPI	Consumer Price Index
EBFM	Ecosystem-based Fisheries Management
FAO	Food and Agriculture Organization
FGBNMS	Flower Garden Banks National Marine Sanctuary
GAJ	Glenn A. Jones
Ha	Hectare
JWCA	Johnson-Wales Culinary Archives
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Association

NYHS	New York Historical Society
NYPL	New York Public Library
PQ	Proquest
SE	Standard Error
TL	Tail length
US	United States
US2014$	US 2014 dollar amount
USGSUSDA	United States Department of Agriculture
USGS	United States Geological Survey
UVC	Underwater Visual Census
W	Weight
Yo	Year old

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CHAPTER I

INTRODUCTION

Scientists and managers are challenged with difficulties in assessing and managing heavily exploited marine resources. Concerns with such assessments include issues with bycatch, gear impact on the environment, and climate change effects to the ecosystem – all of which has led to a more holistic approach in management strategies (King and McFarlane 2003). Most traditional scientific assessments of fishery stocks use statistically random trawl sampling of present populations to estimate sustainable yields and determine the health of a fishery. Although more recently, the trend has migrated towards ecosystem-based management, single species stock-assessment still remains an integral component. Surveys of this type have been routinely conducted for much of the past 100 years.

Beginning in 1950, the National Marine Fisheries Service (NMFS) began compiling commercial landings data and their respective wholesale value. Recently, the scientific community has recognized the importance of reconstructing this type of data to earlier times to understand the interaction between humans and their impacts on marine species prior to the NMFS datasets, (e.g. Pitcher 2001, MacKenzie et al. 2002, Rosenberg et al. 2005, O'Connor et al. 2011, Ferretti et al. 2013) as these early, interactions had intensely and effectively depleted many coastal marine populations (McCauley et al., 2015). Scientists are devising innovative methods to exploit historical data from many disciplines, such as paleoecological, archaeological, historical, and ecological records to illustrate the shifts from once natural trophic baselines of commercially productive systems to the heavily exploited systems we see today (Jackson et al., 2001). Such heavy anthropogenic modification has increased the necessity for understanding historical conditions, in order to provide a robust baseline for assessing future change (e.g. Lotze and Worm, 2008; Ermgassen et al., 2012).The majority of fisheries statistics data is produced using standing stock abundance analyses; although this data is necessary, it does not consider the effects of consumer demand and, in specific cases, conspicuous consumption, in shifting ecosystem baselines – which is the approach of this thesis.

Conspicuous consumption refers to the notion that preferences of consumers are socially mediated, and as such, are often regulated by social rather than economic status (Veblen, 1899; Kapellar and Schutz, 2015). When applied to fisheries, it can be used to infer changes in the availability of marine resources (e.g. Van Houtan et al., 2013). Very few studies have utilized archival data to assess fisheries from a trophic-response level: Levin and Dufault (2010) with cookbooks, Van Houtan et al. (2013) with menus, and Thurstan et al. (2014) with government reports and surveys. Only one study, Jones (2008) with seafood menus, has incorporated prices to track the inflation rate of a dish as it grew in popularity. In this thesis, we complete three individual studies with an over-arching focus on consumer-driven depletion of marine species, such that, we have completed three separate chapters (past, present, and future). As we are arguing for a more holistic approach to fisheries management, we stress the role of consumers in our assessments, as consumer demand drives targeted fisheries. The three chapters are: a wholesale and retail price analysis of a commercially extinct species, Diamondback terrapin, in Chesapeake Bay (1850-1930); the first ecosystem-level price analysis of commercially important marine species from the West Coast of the US (1890-2016); and finally, assess the use of consumer-driven demand to create a pilot-fisheries model as a management strategy for Indo-Pacific Lionfish with a case study in Aruba.

This thesis encompasses multiple disciplines including: biology, economics, history, ecology, sociology, marketing, and fisheries management. Being the first of its kind, the objective of this study was to develop new methods to analyze these largely untapped archival data resources, as well as, analyze the price trends of the economically important marine species. Qualitative and quantitative data was compiled of the various commercial species to determine the exploitation of fish along the coastal United States and to reconstruct 150 years of consumer-driven demand and supply depletion. Finally, the use of consumer demand to re-mediate the invasion of a non-indigenous species was reviewed. Overall this study encompasses past (19^{th} century), present (20^{th} century), and future (21^{st} century) impacts of consumer-driven demand on marine species and ecosystems. Each of the studies presented are stand-alone with an inter-connected theme of utilizing consumer preferences as a complimentary tool for current management strategies.

Chapter two explores a previously disturbed marine resource Diamondback terrapin (*Malaclemys terrapin*) which reached commercial extinction in the early 1920's. This was examined through prices extracted from historical newspapers and menus to create the most comprehensive database for the Chesapeake Bay region. Given the quantity of historical menus and newspaper articles, only those with relevant information were retained. As this was the first attempt to reconstruct the depletion of this marine species, this manuscript is being submitted to a journal widely referenced by historical marine ecologists.

Chapter three examines changes in consumer preferences for marine resources harvested on the West Coast of United States during the 20th century. Here, we overlaid menu prices with the NMFS wholesale data in order to virtually extend this database an additional 50+ years. In addition to this, we used menu prices to construct the first trophic-level assessment based on fishery retail prices. It is an examination of consumer-preference ('Eating down marine food webs') vs. fishing effort ('Fishing down marine food webs'). A manuscript is anticipated to be submitted in a peer-reviewed journal.

Chapter four conceptualizes applying consumer driven-demand in combating the invasive lionfish (*Pterois volitans and miles*)[1] on the coastal United States. Once a marine invasive has become established, there is no way to eradicate them (Mack et al. 2000), therefore, the population must be suppressed to a manageable level. Lionfish were designated as one of the top 15 global threats to marine biodiversity in 2010 (Sutherland et al. 2010), exacerbating the need for control mechanisms. This chapter reviews fisheries management

[1] There are two species of lionfish found along the coastal United States, *Pterois volitans* and *miles*, distinguishable only by genetics (Kochzius et al. 2003, Hamner et al. 2007). When referring to lionfish during this text, it will collectively refer to both species.

literature to synthesize the history of practical approaches and potential short-falls among those strategies. We then present a model that can be used to determine the effectiveness of employing consumer demand as a management approach for this invasive species. We conclude this chapter with a summary of the areas of "research needed" which is anticipated to be included in the PhD research.

Chapter five summarizes the conclusions drawn in chapters two through four and closes with the importance of incorporating consumer driven-demand into management strategies for marine species. It stresses how this application can benefit an ecosystem-based management approach and why it should be strongly considered in future research.

CHAPTER II

CONSUMER DRIVEN DEPLETION OF THE DIAMONDBACK TERRAPIN IN CHESAPEAKE BAY (1850-1930)

Introduction

The National Marine Fisheries Service (NMFS) has compiled commercial fishery landings data and their respective wholesale value since 1950; as such, it is an essential tool for most scientific stock assessments of present fishery populations. However, many marine populations were heavily depleted prior to 1950 (Pauly et al. 2002), which has led to an increasing number of scientific investigations that examined pre-1950 ecosystems and the interaction between humans and marine species (Pitcher 2001, MacKenzie et al. 2002, Rosenberg et al. 2005, Worm & Myers 2003, Lotze et al. 2006, Poulsen et al. 2007, Ferretti et al. 2013, Thurstan et al. 2014). To identify natural baselines of formerly pristine environments, scientists have devised new methods to exploit data from many disciplines, such as paleoecological, archaeological, historical and ecological records (Jackson et al. 2001). In addition, there is a need for studying the role of consumers and the change in consumptive patterns to improve our understanding of serial depletion due to local demands of marine resources on a global scale (Manez et al. 2014). Here we track the commercial extinction of a previously viable Chesapeake Bay resource – Diamondback terrapin (*Malaclemys terrapin*) – by utilizing historical menus, periodicals, and newspaper articles (1850-1930) to determine their consumer-driven withdrawal from markets.

Once the most productive and economically important estuary in the United States, the resources of Chesapeake Bay have been severely depleted over the past 150 years (Coen & Luckenbach 2000). Chesapeake Bay was important in the establishment and growth of human communities in Maryland, Delaware, Virginia, New York, and Pennsylvania because of commercial shipping, generation of electricity, waste disposal, commercial harvesting of wildlife, recreation, and research (Cooper & Brush 1993). Chesapeake Bay is an ideal location to analyze pre-1950 data because it has been settled since the early 1600s (Chesapeake Bay 2002), affording a long history of records never-before examined for scientific research. Diamondback terrapin were a luxury dish in this region, being extinguished in a mere 50 years due to conspicuous consumption. Figure 2-1 outlines the region of Chesapeake Bay with emphasis on the states of interest, important cities, and distribution of Diamondback terrapin. There are seven subspecies of Diamondback terrapin, our study focuses on the Northern species (Figure 2-1 A, B).

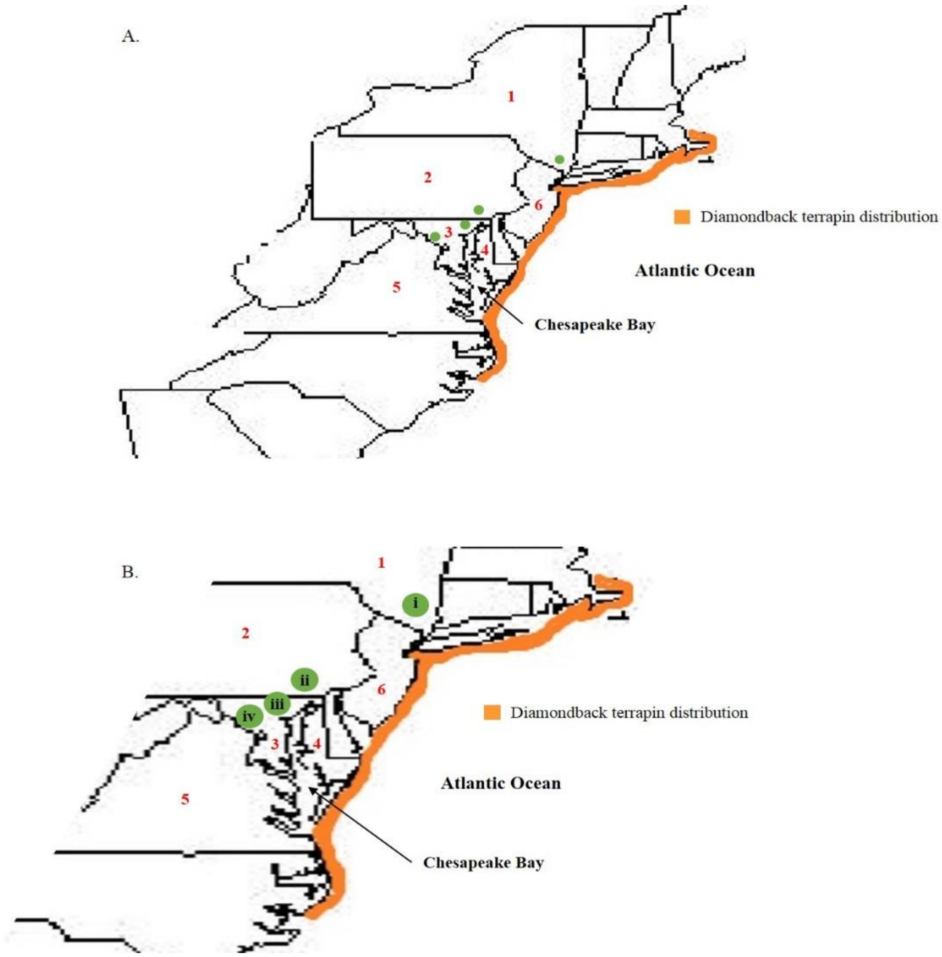


Figure 2-1 A, B. *Map of the US East Coast with emphasis on the Chesapeake Bay, states of interest, and distribution of the Diamondback terrapin.* There are seven subspecies of Diamondback terrapin – our study focuses on the Northern species, with their distribution shown in orange. A) States of interest for this study are highlighted with red text: 1) New York, 2) Pennsylvania, 3) Maryland, 4) Delaware, 5) Virginia, and 6) New Jersey. The major cities are also highlighted with green circles. B) The major cities are signified by the green circles: i) New York City, ii) Philadelphia, iii) Baltimore, and iv) Washington D.C.

M. terrapin ceased to be commercially harvested after the 1920s after nearly 50 years of intense consumer demand. Reconstruction of their consumer-driven depletion can be deduced with the analysis of historic restaurant menus and contemporary newspaper articles. Diamondback terrapin, most popularly served as *Terrapin a la Maryland*, a Madeira wine-laced soup, were heavily demanded by consumers which is reflected in their respective retail prices on menus. The dish stopped being featured on menus after the 1920s, likely owing to the *Volstead Act* (1919), because a key ingredient was no longer accessible. No longer being served in restaurants, they soon disappeared from wholesale fish and game markets. Utilizing this previously unexamined data, we find that as this species popularity rose, so did its inflation-adjusted price. These real dollar increases are some of the largest seen for any marine resource.

Methods

Our study focused on the Northern subspecies of Diamondback terrapin because these were the most highly sought by consumers, their range is within Chesapeake Bay, and they most frequently supplied wholesale markets. Diamondback terrapin species range from the southern United States into the North East; however, contemporary literature suggests consumers demanded the Chesapeake Bay species:

> *"The terrapin…is rapidly becoming a favorite dish with Americans…Philadelphia is the chief market for them, and Baltimore is also a large consumer."* (Anonymous 1874)

Because of this, the states considered for this study were limited to New York, Pennsylvania, Virginia, New Jersey, Delaware, and Maryland (Figure 2-1 A, B). Menus and newspaper articles commonly indicated the location and date of occurrence, as both were often released daily. Restaurants were limited based on their proximity to

Chesapeake Bay, as well as, wholesale markets known to frequently feature the target species.

Previous studies have used nontraditional datasets to evaluate pre-1950 marine ecological systems including – menus (Jones 2008), fishery logbooks (Alexander et al. 2009), and cookbooks (Levin and Default's 2010). Menus, or bills of fare, debuted in the US during the 1820s and became widespread by the 1850s (Jones 2008). Ephemeral by design, they were meant to be discarded and replaced by a new menu daily; however, many examples survive and can now serve as a source for price data of the items they featured. Jones (2008) demonstrated the use of these documents to determine the market behavior of – Canvasback duck, Abalone, and American lobster – and normalized the prices with an appropriate Consumer Price Index (CPI) inflation-adjustment factor. Over 200,000 menus were found to be archived in libraries and historical societies across the US; the largest collections being held at the New York Public Library (~35,000 menus), the New York Historical Society (~25,000), the Johnson and Wales Culinary Archives (~50,000), and the Culinary Institute of America (~30,000).

Menu analyses

Menus were obtained from one online database at the New York Public Library (NYPL), four photocopied collections from NYPL and the New York Historical Society (NYHS), American Antiquarian Society (AAS), the Johnson and Wales Culinary Archives (JWCA), and a private collection of Glenn A. Jones (GAJ). Menus from the collections were classified into one of three types based on content, location, and restaurant class. First, the hotel bill of fare, which traditionally listed the food items offered daily in a hotel; however, the meal was included with the room, therefore, did not have prices. Meals prepared for annual meetings of clubs and societies, constitute the banquet menu, which feature the date of the event and a list of food items served, but lack prices as well. The most useful in this study was the restaurant menu, or bill of fare, which specified the location, date and price of each food item. Approximately 5% of the menus in these collections are of the bill of fare type. A subset of these contained terrapin and were used in this study. Many have been collected or photocopied by GAJ, while others were obtained from digital resources.

Bills of fare advertising a Diamondback terrapin dish from the 1850s – 1930s were selected according to criteria such as: state of origin, dish preparation, and ingredients. These documents can include information on portion size; an important detail when considering the price of a dish. Items were selected on consistency of dish preparation as to retain homogeneity of portion sizes.

Newspaper analyses

Digitized newspaper articles were accessed through library database subscriptions to *American Historical Newspapers, New York Times, The Washington Post, American Periodicals, Newspaper Archives, The Baltimore Sun*, and AAS. The archives were searched according to: date of publication, state of publication, price content, featured species, and commentary on the status of the fishery. Additionally, non-digitized post-1830 books, graphics, and newspapers were examined in person at AAS, as well as, digitized newspaper articles found in Readex only available at AAS.

Newspapers providing most of the appropriate information included: *The New York Times, Washington Post, Baltimore American, Baltimore Sun, The Patriot, The Daily News,* and *Philadelphia Inquirer.* Often, contemporary market details were expressed in the newspaper articles such as, catch of the day, causation for fluctuations of terrapin prices, and/or total catch. Comments from fishermen, locals, or market officials gave an indication about daily fishery and market changes that would otherwise be impossible to validate. These excerpts, collectively with wholesale and menu prices, were used to explain plausible changes in terrapin abundance and market activity.

Approximately 2,000 market prices for terrapin were found in the contemporary literature (Figure 2-2). These prices represent the nominal values that were expressed in the historical newspaper articles.

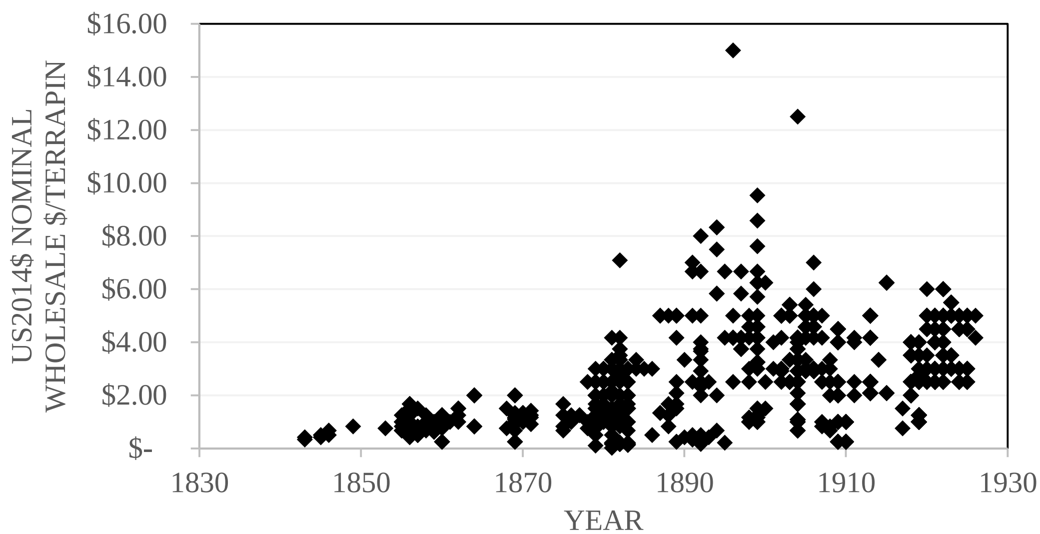


Figure 2-2. *Nominal wholesale $/terrapin per year (1843-1926).* This is used to show the need for determining an effective way to present the data in a way that it is useful.

Inflation adjusting prices

Prices were converted to US2014$ using the *Sahr Consumer Price Index* (CPI) inflation adjustment factor and plotted to demonstrate the trend of the species consumption. To show the necessity for inflation-adjusting prices using the *Sahr CPI*, Figure 2-3 plots the current dollar value without inflation adjustment. This assumes the purchasing power of $0.33 in 1850 would be equivalent to the purchasing power of $10.00 in 2014. If prices were inflation adjusted, the prices would depict a horizontal line at $10.

Data was recorded according to species, year, original price, and CPI price. Although the CPI originated in 1913, economic historians have reconstructed a price index that extends to the 1660's (McCusker 2001). To achieve this, historians examined historical records of wages, property costs and stable priced consumer goods and compared them with prices of similar items of present day (McCusker 2001). The *Sahr CPI* accounts for periods of economic decline and growth, namely economic recession and time of war, and so eliminates possible bias in price per unit ($/unit) conversions during such periods.

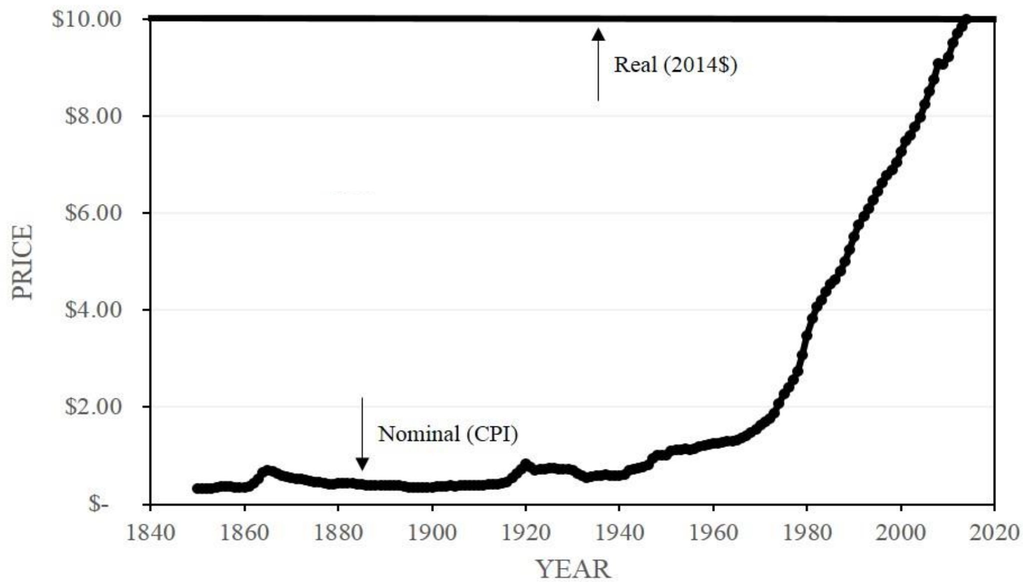


Figure 2-3. *The Consumer-Price Index and its pre-1913 equivalent*. Current dollar values are not inflation adjusted making it difficult to identify any rate of change from the earlier record. The 1850 value is US$0.33 which assumes the equivalent purchasing power of US$10 in 2014. Current dollar prices have increased 30-fold since 1850. Alternatively, the constant dollar can be inflation adjusted to real dollar amounts to track real-time changes. For this plot, the inflation-adjusted dollars would be a straight line value of US$10 for all years 1850—2014. Data was derived from McCusker (2001) and Sahr (2015).

When discussing past prices, historians and economists use the terms nominal and real, where nominal refers to the value expressed in historical monetary terms, while real refers to the adjustment of nominal values to omit the effects of price level changes to reflect general prices in a reference year (Boskin 2008). For this study, we interchange nominal values with terms such as: current, constant, and contemporary. Alternatively, for real values we interchange the term inflation-adjusted prices.

Target species for the study

Constant wholesale Diamondback terrapin prices were extracted from contemporary literature and inflation-adjusted to US2014$ using *Sahr CPI* to determine market behavior. Figure 2-4 shows all of the data collected from newspapers to show the extent of real dollar prices that were available. Great variability exists among the $/terrapin as there were differences in: 1) seasonal vs. calendar years; 2) real vs. nominal prices; 3) size of terrapins sold at market; and 4) a need to represent each year with a seasonal average. We had to sort through all of the real dollar prices according to this criteria before the true market trends could be shown.

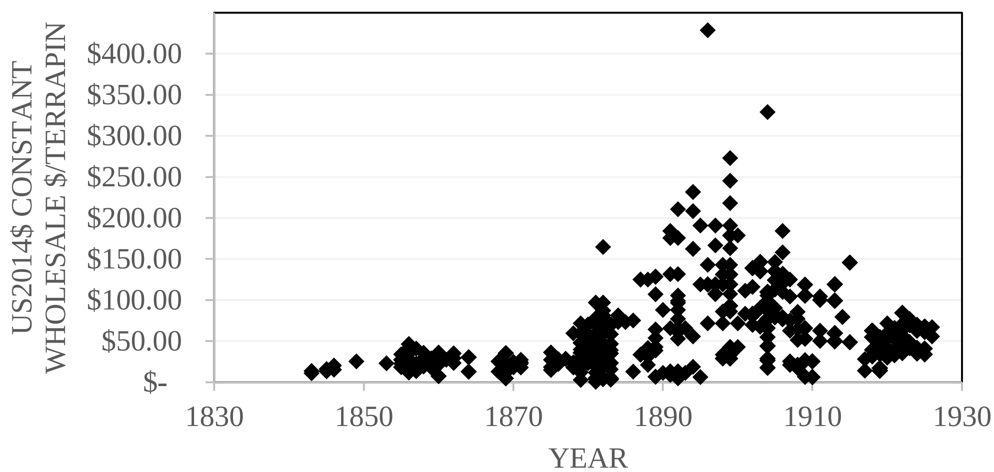


Figure 2-4. *Constant US2014$ wholesale $/terrapin per year in real dollar prices (1843-1926).* This is used to show the need for inflation-adjusted prices as compared to the values seen in Figure 2-2. Real dollar prices better show the true market value.

Seasonal vs. calendar years

The terrapin season can be broken into two different sections: the "market" season and the "harvest" season. Diamondback terrapins were legally harvested from September – April; however, the "market" season was from November – March (Figure 2-5). Terrapins were more frequently captured during colder months because it was a dormant "hibernation" period, therefore, more prices were expected to be seen in the market literature. Assuming the number of prices reflects the purchases, we can see the months with the greatest number of terrapins at market, defining the "market" season.

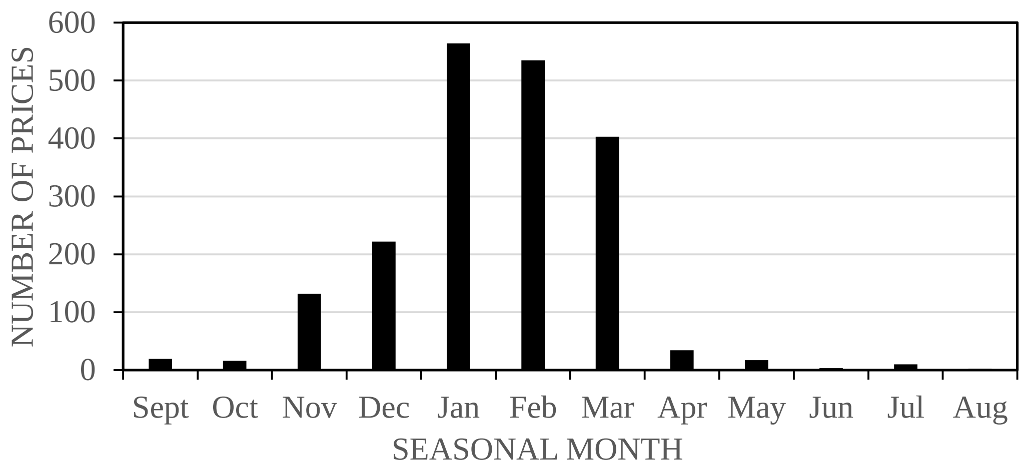


Figure 2-5. *Number of prices for Diamondback terrapin found in extant market literature to show variation among catches in a seasonal year (1843-1925).* The seasonal year extended from September—April and, therefore, all of the prices were categorized accordingly by the date provided on the newspaper excerpt. The "harvest" season extends from September – April, while the "market" season extends from November – March. The "market" season likely exists as terrapins were easier to catch in the winter months, which supports a greater quantity brought to consumer markets.

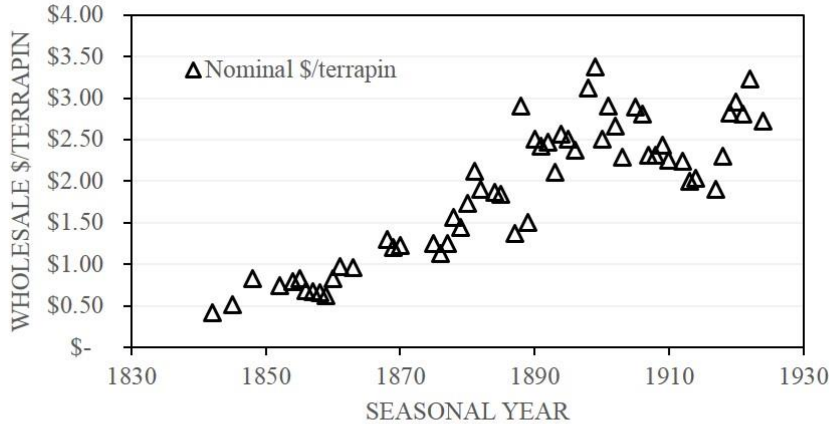
We categorized prices extracted from extant literature to reflect the seasonal "harvest", because the season extended over two calendar years (e.g. September 1880 – April 1881).

Separating the prices into seasonal years were more representative of the terrapin market behavior rather than calendar years.

Real vs. nominal prices

Real prices are adjustments of nominal prices to omit effects of price level changes to reflect the general price changes with respect to a reference year (Boskin 2008). Converting nominal prices to real dollar prices reflects true market changes as the inflation-adjustment factors account for times of economic hardships, which would otherwise influence the nominal prices and show lower prices relative to years that did not experience the same hardships (Figure 2-6).

A.



B.

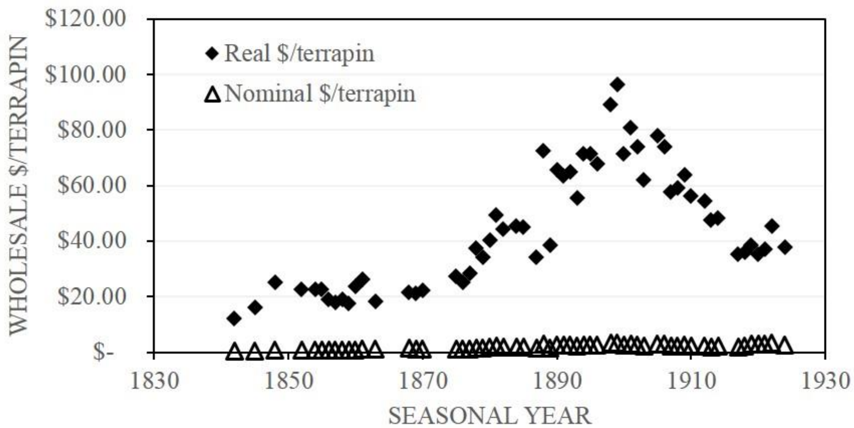


Figure 2-6 A, B. *Constant average wholesale $/terrapin per seasonal year in nominal and real dollar prices (1843-1924).* A) average nominal $/season for individual terrapins, notice prices range from US$0.38 in 1843 to US$2.75 in 1924, with the greatest price being US$4.17 in 1895. B) comparison between real and nominal prices on the same scale to show the effect of inflation-adjusted prices. The trend is the same, however, the real prices are much higher and better indicate market behavior.

The trend experienced by both nominal and real values is the same, however, the real prices are much higher and better indicate the terrapin’s true market behavior.

Size classification

Prices varied among the male (bull) and female (cow or heifer) terrapins, as well as, by the size sold. Females were preferred over bull terrapins as they were larger and may be egg bearing (cow):

> *"The females only attain [6.5 – 7 inches in] size, and are therefore the most desirable, a female, or "cow" terrapin…is termed a 'full count in the trade…Those measuring five or six inches along the lower shell are termed 'heifers'…The males or 'bulls' have scarcely any marketable value"* (Anonymous 1879).

These fluctuations were reflected in prices with bull terrapins affording values much lower than larger females (Figure 2-7). As smaller terrapins were less desired, their marketable price decreased materially (Anonymous 1875).

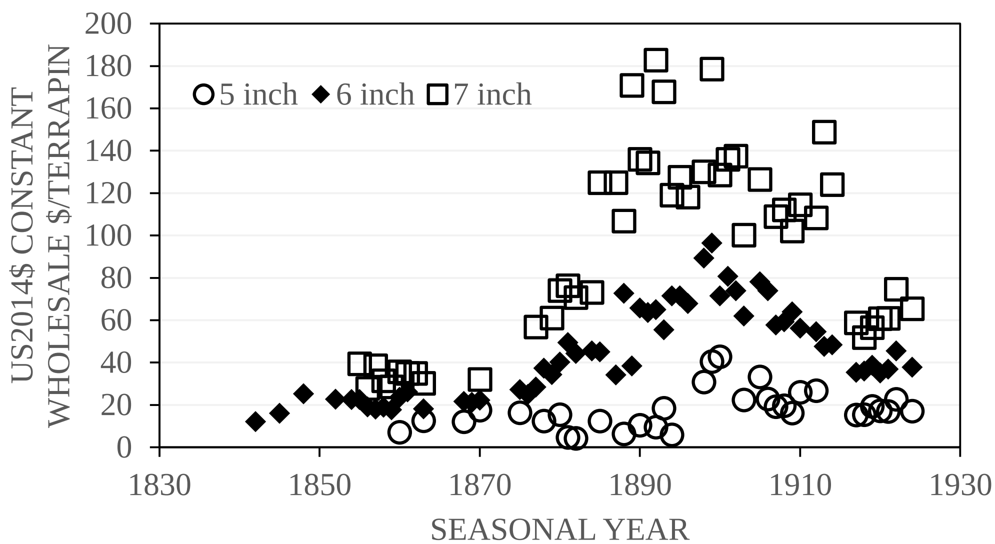


Figure 2-7. *Average US2014$ inflation adjusted $/terrapin for each seasonal year according to size variability (1840-1925).* Average of price values differentiated by size extracted from contemporary literature for $/terrapin for each seasonal year inflation adjusted to US2014$.

In many cases, the size and/or gender of the reptiles were displayed in newspaper articles, making it easy to separate prices (Figure 2-8).

> *"Terrapin – Diamondbacks, 7 inches, per dozen $55a60; do., 6 inches, per dozen, $35a36; do., 5 inches, per dozen, $15; do., sliders, per dozen, $2.50a3."*

Figure 2-8. *Nominal prices with size indication as shown in contemporary market literature (1906a).* Section from a Stock Quote in the *Baltimore Sun* on March 21, 1906 that displays Diamondback terrapin for sale according to size**.** Nominal prices shown in a newspaper article that displays the Diamondback terrapin with prices according to size. Each size and price is highlighted for ease of interpretation. Prices in US2014$ are $1,447.31 - $1,578.95, $921.05 - $947.37, and $394.74, for 7, 6, and 5 inch terrapins, respectively (Anonymous 1906a).

When prices were given for multiple sizes, the median prices given for the 6inch were utilized in this study, as they were the most commonly purchased. If the size was not specified within the literature, prices that were within the same nominal price range and year were used. They were converted to $/each if sold by the dozen, and then all prices were inflation adjusted using *Sahr CPI* adjustment factors for corresponding years. The mean of prices collected for each seasonal year were obtained to find annual averages.

Seasonal averages

To represent each year with an individual price, an annual average was obtained for each seasonal year (Figure 2-9). This omitted bias that may exist with price variability and enhanced the ability to interpret the true market trends. For the rest of this paper, we discuss the results from the seasonal averages of six inch terrapins. We report the prices as $/terrapin as they were sold in wholesale markets by the individual terrapins rather than by weight (Anonymous 1906) and the average weight of an adult terrapin is 1lb (DEEP 2015).

Results and Discussion

Seasonal averages of individual terrapins reported at six inches in length were used to evaluate the wholesale market trends (Figure 2-9). Prior to 1880, real dollar prices remained relatively stable, following the inflation rate closely suggesting there was a broad balance between supply and demand (Figure 2-9). After 1880, the cost to purchase a terrapin at a wholesale market experienced an eight-fold increase. This also corresponds with market literature showing a change in sales to include size specifications, likely an indication of an increase in market demand.

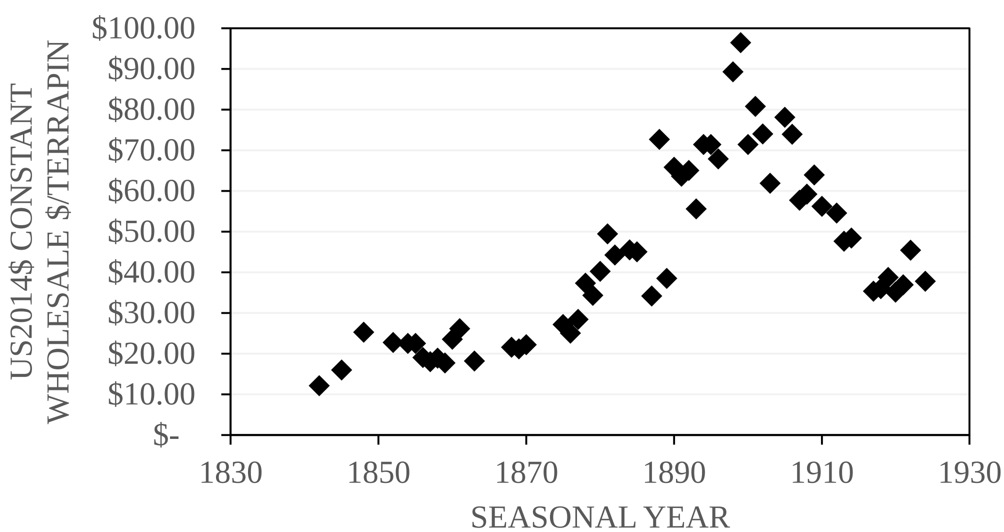


Figure 2-9. *Average US2014$ inflation adjusted $/terrapin for individual annual seasons (1840-1925).* Average of price values extracted from contemporary literature for $/terrapin for each season inflation adjusted to US2014$.

In contemporary market literature, the price and quantity sold for terrapin was specified. A transition occurs in both, prices and quantities of terrapin sold, during the period we examined. Terrapins can be categorized in three different periods: early (pre-1880), mid (1880's to early 1900's), and late (post-1909), with respect to how they were sold. During the early period, Diamondbacks were sold by price per dozen ($/dozen) at the forefront of their exploitation. Following the 1880's, they began being sold as $/dozen with a size indication (e.g. 5inch, 6inch, 7inch, counts) which coincides with the observed price increase (Figure 2-9). In the late period, terrapins transitioned to being sold as $/each with a size indication, which corresponds with an observed decrease in price (Figure 2-9). From extant literature, this decrease in price is likely due to diminishing terrapin populations and loss in favor among patrons:

> *"Not numerous anywhere nowadays, it is still in Delaware and Chesapeake Bays that they are oftenest captured, and there, too, they are of better quality – as food – than in the warmer waters further south...two things now threaten their fame as providing the choicest dish for stately banquets – the difficulty of getting the sherry supposed to be essential for their proper preparation for the table, and the asserted dying out of people who care enough about what they eat to spend for a single dish what terrapin long have cost"* (Anonymous 1920).

Variability exists in the number of useful and available newspapers that provide wholesale price data. As newspapers were often ephemeral, the availability of such items for this study varied among years – a limitation we acknowledge. For example, we retrieved ninety-two prices for seasonal year 1918, but only two prices for seasonal year 1919. Although these years are consecutive and present comparable seasonal averages, we still acknowledge that this could have potentially negative outcomes for other species. However, it did not appear to be an issue for this study.

Contemporary menus were also utilized to compare the retail (consumer) vs. wholesale behavior of Diamondback terrapin (Figure 2-10). As with market data (Figure 2-9), menu real $/dish was relatively constant until 1880. An 8-fold increase in the real $/dish was experienced from 1880 – 1910. These prices began to fall after the late 1900's into the 1920s, as did the market value. Although gaps in the data remain due to the nature of ephemeral documents, this is the most comprehensive price analysis for Diamondback terrapin prior to 1950.

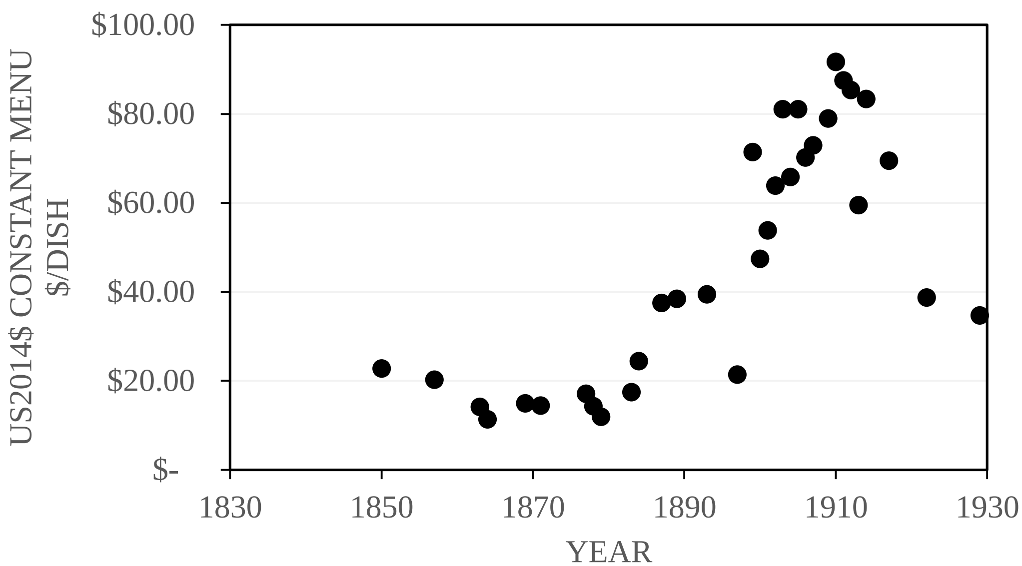


Figure 2-10. *Inflation adjusted price values for menu $/dish of Diamondback terrapin served as Terrapin a la Maryland, Terrapin Soup, or Stewed terrapin.* All prices extracted from bills of fare are adjusted to US2014$ equivalent.

We hypothesize the retail menu prices began falling after the passage of the *Volstead Act* (1919), as a key ingredient, Madeira, was no longer available to chefs. Both market and menu datasets follow nearly identical patterns. Wholesale market prices for terrapins had a more defined incline in prices after the 1880s, which can be expected as market prices likely increased prior to menu prices. The reason for price increase is well reflected in the contemporary literature, suggesting it was determined by consumer preferences.

"[Terrapin] is the most delicate and the most expensive dish that appears on an American table. No man who is a good eater would give a dinner-party without it. The terrapin and canvas-back duck must be on a table that makes any pretensions to correctness." (Anonymous 1884).

Diamondback terrapin were not always a favorite among consumers, as it was once a food fed to slaves:

"[The] terrapin's popularity is very recent. Old records show that the slaves of this state used to rebel because they were given terrapin instead of pork." (Anonymous 1887).

This likely explains why the prices relatively tracked the inflation rate at the beginning of their exploitation, because the supply was broadly meeting the demand. The ability for terrapin dishes to transform from a low quality food supplement to luxury item in a short time, supports the notion that it was consumer preference that led to this transformation. Once it was served, and represented wealth and luxury, there was no price too high to pay:

"To-day terrapin are so scarce and costly that only kings and money kings at that, can afford to eat them" (Anonymous 1906b).

As the consumer demand increased, terrapin supply subsequently suffered. Consumer concerns for the reduction in terrapin stocks began to appear in contemporary newspapers in the 1890's – as a result the prices began to experience dramatic increases in wholesale (Figure 2-9) and retail (Figure 2-10) markets. This relationship is a strong indication of conspicuous consumption:

> "*For some time the appalling fact has been staring the 'high livers' and epicures in the face that diamond-back terrapin are becoming extinct…the increasing demand for them, and the wholesale capture of old and young have done their inevitable work in thinning out their number*" (Anonymous 1892b).

The likelihood of their commercial extinction and epicurean demise continued through the early 1900's, which is reflected in their high prices. Towards the late 1910's and into the 1920's the prices began declining on menus and the wholesale markets. We hypothesized that their disappearance was more complex than a mere reduction in stocks, and concluded it was also a consequence of a decline in favor among epicures (Anonymous 1920).

It is also apparent the *Volstead Act* (1919) affected Diamondback terrapin's appearance in wholesale and retail markets; however, it could be argued that this may have saved their species. Consumers could no longer attain an important ingredient for this popular dish, therefore, reducing the demand. Terrapins scarcely returned to the wholesale and retail markets once Prohibition was repealed, likely because consumers no longer favored it. This may have allowed natural populations to begin recovering.

Subsequently, Diamondback terrapins were often complimentary meals with Canvasback ducks at restaurants. These waterfowl were no longer allowed to be sold in wholesale or retail markets following the passage of the *Migratory Bird Act of 1918*. We hypothesize this, in congruence with diminished stocks (Anonymous 1926), change in consumer preference, and Prohibition (Anonymous 1923), eventually led to the terrapins disappearance from markets.

Diamondback terrapins were a short lived, high priced marine resource that are no longer seen in wholesale or retail databases today (Figure 2-11). Figure 2-11 shows the inflation-trends of wholesale (A) and retail (B) market data as they relate to the inflation-adjusted prices. Diamondback terrapin showed the greatest changes in inflation-adjusted prices experienced by any marine species, sustaining a 5.5-6% increase above the inflation rate over approximately 20 years for retail and wholesale markets, respectively.

A.

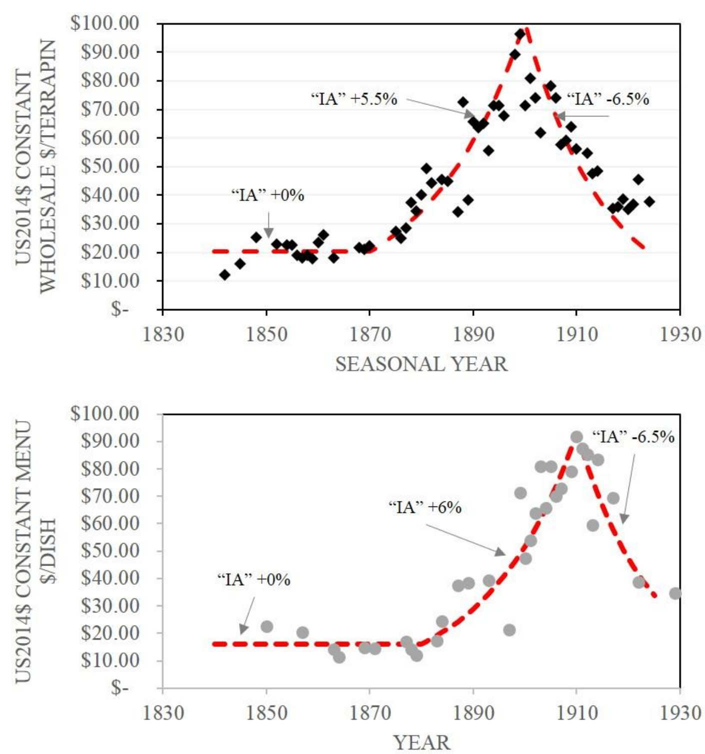


Figure 2-11 A, B. *The inflation-trends for wholesale (A) and retail (B) market trends for Diamondback terrapin.* These figures show the trends as they relate to the inflation-adjusted (IA) prices, therefore, where it is indicated "IA" +0%, this means the prices were following the inflation rate. Where it is indicated "IA" +5.5-6%, this shows that the prices were 5.5-6% higher than the inflation rate, respectively. "IA" -6.5% indicates the prices were declining a 6.5% slower than the inflation rate. We can see that terrapins show the greatest increases in inflation-adjusted prices experienced by any marine species.

The NMFS commercial stock landings does not indicate the true market trends of this species, as they were no longer a food commodity when these landings were established. Terrapin can be compared to species today, as similar trends are being seen, such as with Patagonian toothfish (*Dissostichus eleginoides*) and Red Snapper (*Lutjandes*).

Conclusion

The efforts to understand the consumption of fisheries is extremely limited (Van Houtan et al. 2013); however, it may prove to be valuable, as consumer demand drives targeted fishery harvests. Conspicuous consumption refers to the notion that preferences of the consumers are socially mediated, and as such, are often regulated by social rather than economic status (Veblen 1899; Kapellar & Schutz 2015). Restaurant menus document seafood consumption and consumer preference, offering the ability to indirectly track wild population abundances, as well as, distinguish the value of different species in the past (Van Houtan et al. 2013). Menus are limited, such that, they do not provide additional information about the particular fishery. However, delving into contemporary literature affords the ability to explain these price variations as they were often published in daily newspaper articles and periodic journals. Recent digitization of this contemporary literature (e.g. newspaper articles, journals, and periodicals) has made it effective and obtainable for discovering wholesale market trends, legislative actions, and daily/annual fishery stock changes. In conjunction with prices extracted from menus and wholesale markets, extant literature was utilized to explain behavior exhibited by the cost data.

On the basis of available historical evidence, these menu and newspaper analyses have resulted in the reconstruction of a consumer driven data series for Diamondback terrapin. Our study of Chesapeake Bay consumer driven commercial harvest is an example of historical ecology that demonstrates a 'shifting baseline' scenario by revealing the previous existence of a marine ecosystem very different from that which is known in the present. Anthropogenic manipulation of the ocean has been ongoing for centuries; contextualization of these historical perspectives are crucial when determining future management of marine resources (Bolster 2006). Historically, fishing was a sustenance removal from oceans on small boats with simple gear (Pauly & Watson 2003) constrained by inaccessibility to remote offshore locations (Berkes et al. 2006). During a time when oceans were believed to be inexhaustible (Huxley 1884), in years prior to 1950 and the establishment of NMFS, society was concerned with the extinction of this brackish-water turtle.

Conspicuous consumption is a new sector of fisheries ecology, yet it is shown here to be effective in determining market behavior of commercially valuable species prior to the establishment of fisheries catch statistics (e.g. NMFS – 1950). Without such data, some species would go unnoticed as being an important food commodity. The trends Diamondback terrapins faced, of rapid consumer popularity and rapid population decline, are experienced by present – day species. Pauly and Watson (2003) reported commercially desirable species stocks were greatly reduced in haul capacity, as well as, the length of the individual fish being caught. The same fate was experienced by the Diamondback terrapin (Anonymous 1892b) in less than two decades following their infamous rise to epicurean fame. It is unlikely to predict the fate of such fisheries strictly using historical data. However, utilizing this never-before examined data, with current management approaches, will afford a more robust database to assess the impacts to present fishery stocks and grant a better prediction for the fate of such fisheries. This may aid in the overall protection of current and future diminishing populations.

CHAPTER III

RECONSTRUCTION OF CONSUMER-DRIVEN EXPLOITATION OF COMMERICAL FISHERIES ON THE US WEST COAST (1890-2016)

Introduction

Commercial fishery catch statistics and their respective wholesale values began being compiled by the National Marine Fisheries Services (NMFS) in 1950. Since then, this information has been instrumental for scientists and managers in determining the health of fisheries, standing stock analyses, and in establishing maximum sustainable yields. Although this seems effective for managing present stocks, it is known that many fishery populations were heavily depleted prior to this date, thus, suggesting the need for a more robust approach to better estimate the current health of a fishery (Jackson et al. 2001, etc.). Scientists have shown considerable interest in transitioning to Ecosystem Based-Fishery Management (EBFM) approaches by compiling various ecosystem indicators that affect fishery populations; however, confusion as to what constitutes an ecosystem indicator is evident (Pauly and Watson 2005). We propose that retail price assessments of historical fisheries be incorporated as an additional indicator when determining the health of a fishery – as is the approach of this thesis.

Another important component to our approach is the role of consumers in the marine food chain. An integral element that defines the structure of marine ecosystems is predation (Madin et al. 2016, Darwin 1876), but humans rarely consider themselves a top marine predator when choosing to eat fish and/or fishery products. Retail prices extracted from historical menus can be used to hind-cast fishery exploitations, such that, they can be normalized to the NMFS commercial catch statistics to extend this database up to 100 years into the past (Jones 2008). Jones (2008) showed single species analyses could be successful with: Abalone (West Coast), American Lobster (northern East Coast), and Canvasback duck (central East Coast).

This study is the first attempt to utilize historical menus to track fishery price changes within the entire ecosystem of the US West Coast (Figure 3-1). The approach of this study was to track price changes from several species within this ecosystem to determine if it is as effective as a single-species analysis. This study also includes the first attempt to utilize menus to assess price changes according to trophic level.

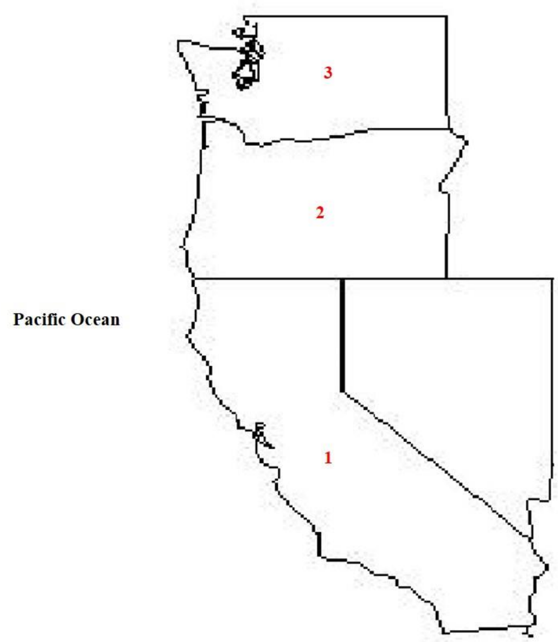


Figure 3-1. *Map of the West Coast of the United States highlighting the states of interest for this study.* States were limited in this study to 1) California, 2) Oregon, and 3) Washington.

It is important to note that since the 1970s, in general, the US has relied much more heavily on aquaculture fisheries. Because of this, the NMFS data may be an appropriate source for fisheries research prior to this date (1950-1975) as they report wild-caught commercial catch statistics. It can be broadly assumed that species prior to the establishment of aquaculture farms were wild caught species and, therefore, the menus will reflect wild caught fish – this will be the years of overlap to focus on when interpreting the results. Following 1970, restaurants may have been serving aquaculture grown fish, rather than wild caught, which would reveal a discrepancy between the menu data and NMFS data (e.g. Salmon and Abalone).

Managers and scientists can then use these historical retail price changes as an indicator in their EBFM practices to improve current management strategies. Here we track retail price changes of commercially important fish species from the West Coast of the United States in the 20th century. Another study currently underway is looking at the Northeastern United States where menus extend to the 1850's (Jones in progress). We also accomplish the first ecosystem-level evaluation of fishery price changes by completing a trophic assessment of fish species presented on these menus. This is the first study to compare consumer-preference ('Eating down the food web') with fishing effort ('Fishing down marine food webs') through the use of historical menu prices.

Methods

The idea for this study was to create a virtual NMFS dataset that extends prior to its establishment in 1950 by comparing wholesale NFMS prices with historical retail prices. There is more early menu data available than recent (i.e. greater quantity pre-1950 menu vs post-1990), therefore, it is more effective for constructing pre-1950 datasets. The quality of the NMFS commercial catch statistics admittedly varies in relevance and accuracy among different species and years. This may be influenced by the manner in which these resources are reported, rendering variability in accuracy with respect to the commercial harvest or the wholesale dollar value. After the 1970s, the NMFS dataset may even be less accurate, as reliance on fishery aquaculture production greatly increased in the US.

This study focuses on the West Coast ecosystem of the US, therefore, menus were limited to the states of California, Oregon, and Washington (Figure 3-1). Menus commonly indicated the location and date of occurrence, as they were often printed daily. Menus were refined according to their proximity to the coast, such that, coastal cities were preferred for the purpose of this study. They were also evaluated relative to social strata, as prices were higher for the less-common luxury restaurants. Approximately 320 menus were used in this study.

Studies have used nontraditional datasets to evaluate pre-1950 marine ecosystems including – menus (Jones 2008), cookbooks (Levin and Default 2010), and fishery logbooks (Alexander et al. 2009). Each of which have shown these historical databases are effective in determining the fate of previously exploited species. In the US, menus debuted during the 1820s and became widespread by the 1850s (Jones 2008). Often printed daily, these menus were ephemeral by design and discarded after a single use; however, many still exist as they were often saved for remembrance purposes. These documents are now a source for price data of featured items and be can used to demonstrate respective market behavior.

Over 200,000 menus are archived in libraries and historical societies across the US with the largest collections being held at the New York Public Library (NYPL, ~35,000 menus), the New York Historical Society (NYHS, ~25,000), the Johnson and Wales Culinary Archives (JWCA, ~50,000) and the Culinary Institute of America (CIA,

~30,000). Menus from these collections are classified as to one of three types: 1) a hotel bill of fare, which included seafood items but may not always include prices as may be included in the room cost. 2) A banquet menu associated with an annual meeting of a society or organization which lists the food items served but also lacks prices. And 3) the restaurant bill of fare, which is the most useful, as it includes prices and may have featured portion units. Less than 5% of these archived menus are of the priced restaurant type, and a very small subset of these were from West Coast menus.

Of the 320 menus used in this study, 19 were from JWCA while the other 301 were from the personal collection of Glenn A. Jones (GAJ) which includes both physical and photocopied menus. Bills of fare advertising fishery dishes from 1890 – 2016 were selected according to state, price relative to social strata, dish preparation, and ingredients. Prices were converted to US2014$ using the *Sahr Consumer Price Index (CPI)* inflation adjustment factor and plotted to demonstrate a time series of trends in species consumption. To verify the necessity for inflation-adjusting prices using the *Sahr CPI*, Figure 3-2 plots the nominal dollar value without inflation adjustment. This figure shows the nominal purchasing power equivalent to the purchasing power of $10.00 in 2014. For example, $0.33 in 1850 had the same purchasing power as $10.00 in 2014. If prices were inflation adjusted, the prices would depict a horizontal line at $10.

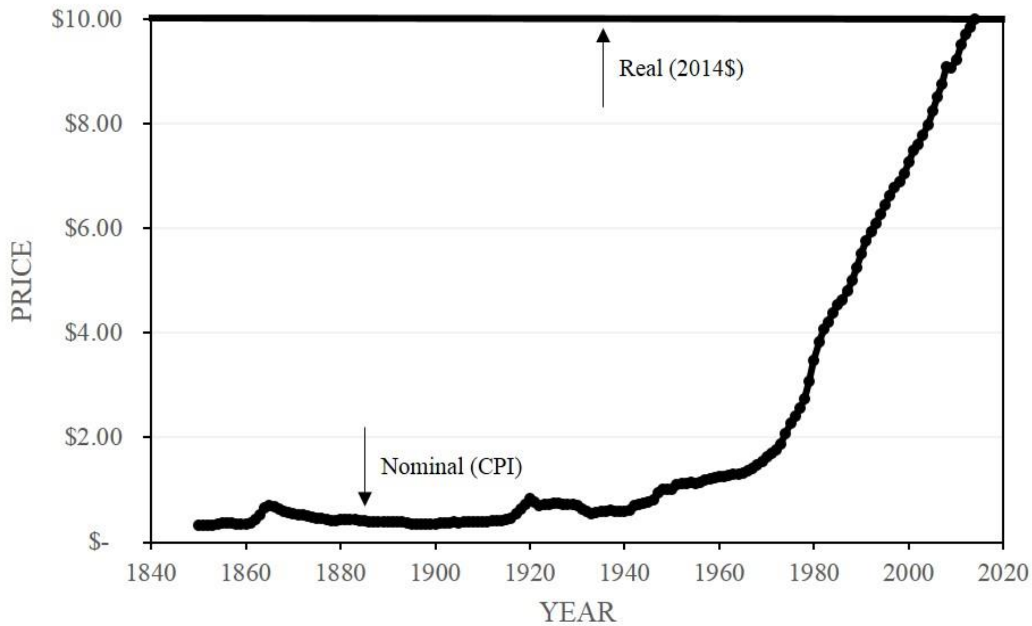


Figure 3-2. *The Consumer-Price Index and its pre-1913 equivalent*. Current dollar values are not inflation adjusted making it difficult to identify any rate of change from the earlier record. The 1850 value is US$0.33 which assumes the equivalent purchasing power of US$10 in 2014. Current dollar prices have increased 30-fold since 1850. Alternatively, the constant dollar can be inflation adjusted to real dollar amounts to track real-time changes. For this plot, the inflation-adjusted dollars would be a straight line value of US$10 for all years 1850—2014. Data was derived from McCusker (2001) and Sahr (2015).

Although the CPI originated in 1913, economic historians have reconstructed a price index that extends to the 1660's (McCusker 2001). To achieve this, historians examined historical records of wages, property costs and stable priced consumer goods and compared them with prices of similar items of present day (McCusker 2001). The *Sahr* CPI accounts for periods of economic decline and growth, namely economic recession and time of war, and so eliminates possible bias in price per unit ($/unit) conversions during such periods.

When discussing past prices, historians and economists use the terms nominal and real, where nominal refers to the value expressed in historical monetary terms, while real refers to the adjustment of nominal values to omit the effects of price level changes to reflect general prices in a reference year (Boskin 2008). For this study, we interchange nominal values with terms such as: current, constant, and contemporary. Alternatively, for real values we interchange the term inflation-adjusted prices.

Data was recorded according to species, year, original price, CPI price, portion units, location, and preparation. These criteria were used to complete species-level cost analyses, as well as, ecosystem-level price assessments. Some of the menus contained information about portion units; an important component when evaluating the price of dishes. All seafood item preparations were recorded; however, these were further refined according to consistency of dish preparation and species to retain homogeneity of portion sizes. These datasets are complicated when various preparation styles exist (Figure 3-3).

For example, clams were featured on 51 menus, in 14 different preparations, with 10 different specific types (e.g. Littleneck, Razor, California), and in 14 cities. These entries are further complicated by portion unit sizes (e.g. dozen vs. half dozen) if present. In order to obtain a representative retail price, each of the 49 species had to be evaluated according to all of these criteria. Figure 3-3 shows all of the data collected for clams represented by the most common preparations, respectively.

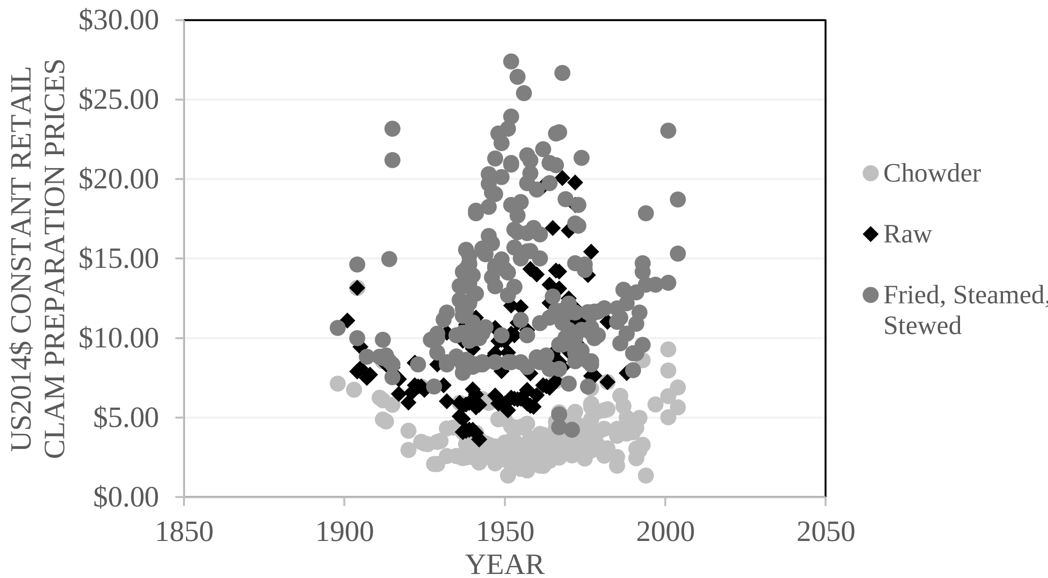


Figure 3-3. *Inflation adjusted US2014$ retail menu clam data classified by their respective preparations.* No additional filters or modifications have be done in this figure, therefore, price variability exists within the preparations as they have not been adjusted for portion sizes.

Three distinct variations in price for preparation exist within this dataset (Figure 3-3), although they all follow the same trend. These prices can be further modified by annual averaging all of the data points for each preparation (Figure 3-4). Prices must be further normalized according to portion units, if applicable. Raw clams are the most useful preparation, as these retail prices most closely reflect the cost for the clams, rather than higher prices for ingredients and cooking time. Therefore, we chose to use raw clams as our representative preparation. Raw clams were sold by the dozen, or half dozen, which was often mentioned on the menus. If the portions were not specified on menus, prices were compared to similar prices from the same region and year in order to assign a portion unit for normalization.

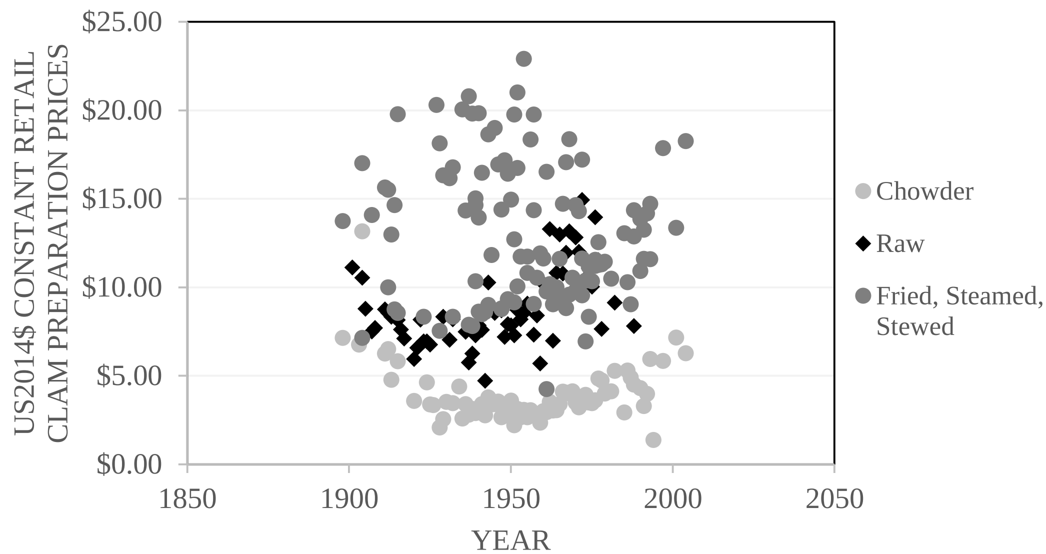


***Figure 3-4**. Annual averages of inflation-adjusted US2014$ for clam preparations featured on US West Coast menus.* Price variability remains among each preparation as there has been no normalizing for the portion units.

Raw clams were all normalized to $/each to be more consistent with NMFS datasets ($/lb). The prices were then annual averaged to reduce price variability that may exist because of restaurant or location (Figure 3-5). These variables were also evaluated (i.e. restaurant and location) to determine if price bias existed, but no differences appeared to be present. These prices were then compared to the NMFS dataset for Pacific Littleneck Clams (*Protothaca staminea*) as this species is local to the US West Coast and the majority of clam types specified (~30% Littlenecks, ~60% un-specified, and ~10% other species) on menus were Littlenecks (Figure 3-5). The other species mentioned on menus were eliminated from the final figure as those prices were much higher than Littleneck clams. All other marine species recorded had to undergo similar evaluations as demonstrated with the clam data.

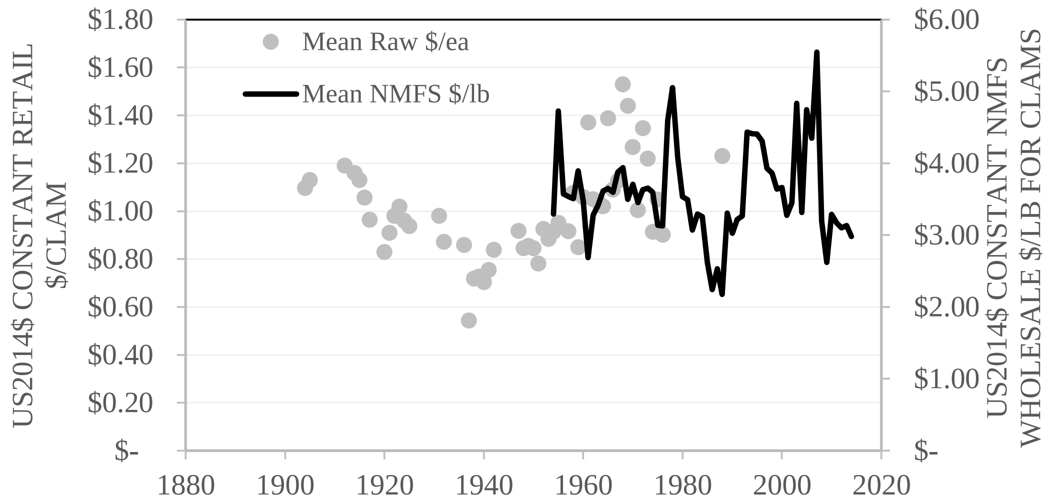
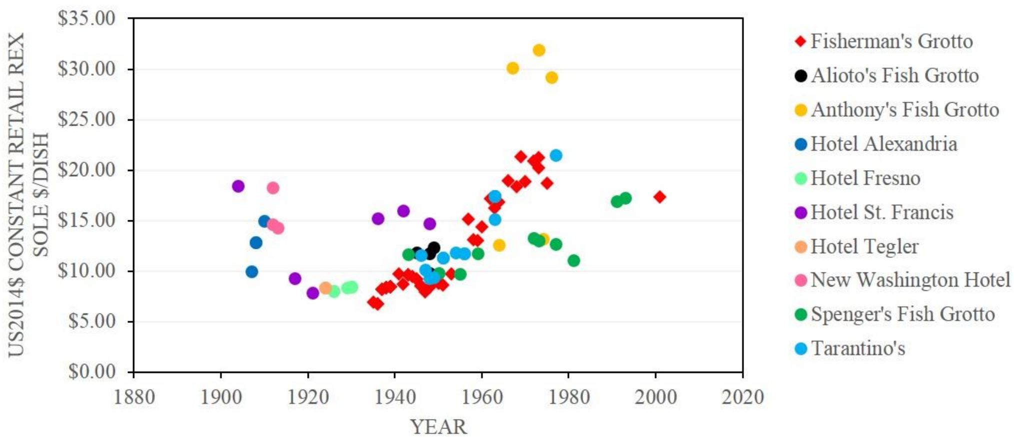


Figure 3-5. *Annual average US2014$ inflation adjusted $/clam for raw clams featured on US West Coast Menus compared to NMFS US2014$ inflation adjusted $/lb for Pacific Littleneck clams.* The two datasets are compared on different scales to show the consistency of retail menu prices with wholesale NMFS prices. In effect, the data can be extended 50 years earlier than the start of the NMFS data that began in 1950 (p-value <0.01).

Prices extracted from menus were compared according to restaurant and location to determine if price variability existed. Although clams did not exhibit this feature, several of the fish species did. We use the Rex Sole dataset to demonstrate the benefit of determining an adjustment factor and normalizing the retail prices to a particular menu (Figure 3-6 A, B).

A.



B.

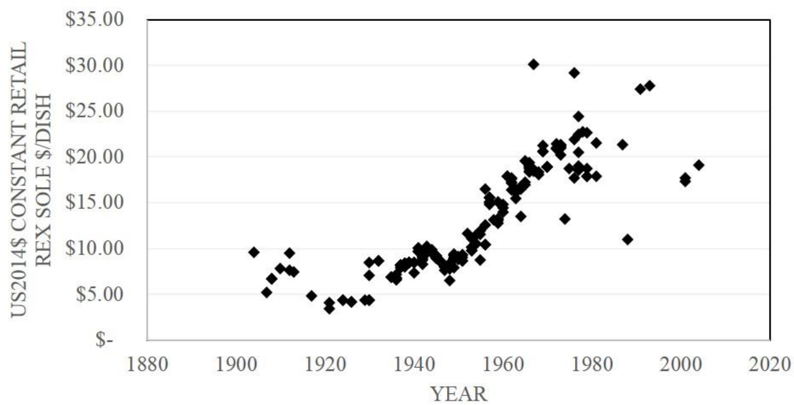


Figure 3-6 A, B. *Comparison between non-normalized prices of Rex Sole (A) to normalized Fisherman's Grotto prices of Rex Sole (B) to show the necessity for such adjustments.* Restaurants that showed a 1:1 ratio with Fisherman's Grotto prices were not included (i.e. Bernstein's Fish Grotto, Castagnola's, Exposition Fish Grotto, Jack's Restaurant, Oyster Loaf, Sam's Grill, and Tadich Grill) on this figure for ease in interpreting the differences experienced by other restaurants or hotels. These prices did not require normalization. Prices were normalized to Fisherman's Grotto restaurant prices because this was the most robust dataset, with nearly each consecutive year from 1935 – 2004 being represented.

We chose to normalize menu prices for fish species (i.e. Rex Sole, Sand dabs, Salmon, Sea bass, and Barracuda) to the restaurant Fisherman's Grotto because this was the most robust dataset, with nearly every year being represented from 1935-2004. Prices from each of the restaurants were compared to Fisherman's Grotto to determine an adjustment factor (if needed). Many restaurant prices exhibited a 1:1 ratio with Fisherman's Grotto and, therefore, did not require any adjustments. However, if prices were lower or higher, they were adjusted to be more consistent with the Fisherman's Grotto prices.

To determine this adjustment factor, the prices for each menu (e.g. Fisherman's Grotto and Anthony's Fish Grotto) were compared by the year of occurrence. The prices for the compared menus were then adjusted accordingly as seen in Figure 3-6 B. Following these analyses, the prices were annual averaged to be compared to the NMFS dataset.

Additionally the NMFS data and menu data were assessed for stationarity and co-integration using Dickey-Fuller statistics. Dickey-Fuller statistics test that each of the individual series (i.e. NMFS and menu data) are non-stationary, such that, there exists some trend (Wooldridge 2016). It then tests that the regression of the two series are stationary, suggesting they are moving together through time, and are therefore co-integrated (Wooldridge 2016). An example of stationary and non-stationary datasets are provided in Appendix A (Figure A-1). The equations for the Dickey-Fuller statistics are provided:

1) $\Delta P = \beta_0 + \beta_1 * P_{t-1}$

2) $NMFS = \beta_0 + \beta_1 Menu$

Where equation 1 represents the test for stationarity and equation 2 represents the test for co-integration. In equation 1, ΔP is the change in prices for each data series, β_0 is the slope, β_1 is a constant, and P_{t-1} refers to the lag in prices. In equation 2, NMFS is the regression of the datasets, β_0 is the slope, β_1 is a constant, and Menu refers to the menu dataset which is regressed with the NMFS data. Our null hypothesis and alternative hypotheses are as follow:

$$H_0\colon \beta_0 = 0$$

$$H_A\colon \beta_0 \neq 0$$

Such that, the null hypothesis states the datasets are stationary, and the alternative hypothesis being they are non-stationary.

Price changes were found for species across varying taxonomic groups which we categorized according to the type of organism and habitat use: invertebrate mollusks, invertebrates, demersal fishes, small pelagic fishes, medium pelagic fishes, and large pelagic fishes. Species were categorized to a trophic level relative to their diet, size, and habitat use. This is the first attempt to use fishery prices extracted from menus to reflect the concept of ‘Eating down the food web’ refined from Pauly et al.’s ‘Fishing down the food web’ (2000). Respective real-dollar prices of fishes assigned in each trophic level group were averaged for a time-series trophic-level price assessment.

Results and Discussion

A total of forty nine species were recorded from the West Coast menus, but varied in the number of entries. Many did not sustain enough values to accurately represent the species or did not contain prices that occurred prior to 1950 – rendering them non-useful to hindcast the NMFS dataset (Appendix A). Representative species from each group (i.e. invertebrate mollusks, invertebrates, demersal fishes, small pelagic fishes, medium pelagic fishes, and large pelagic fishes) are presented in this section. Additional tables listing the other species are found in Appendix A with rationales for their exclusion from further analyses. Those representative species for each group: Oysters and Abalone, Crab, Sand Dabs and Rex Sole, Mackerel, Salmon and Sea Bass, and Swordfish and Barracuda, respectively. Each of the species inflation adjusted prices are compared to the NMFS data.

Invertebrate mollusks

There were six species featured in the invertebrate mollusk category. We chose to represent this category with Abalone (*Haliotis spp.*) and Oyster (*Crassostrea virginica)*. Our results for Clams (*Protothaca staminea*) are also presented in the methods section. The menu prices were annual averaged and overlaid with NMFS data for all Abalone species to be consistent (Figure 3-7). Abalone prices briefly followed the inflation rate at the beginning of their exploitation, but began rising faster than the inflation rate in the 1930s. Menu prices experienced nearly a 5-fold increase since the beginning of their exploitation. Menu data tracks the NMFS data well until the 1970s, where the NMFS data begins showing drastic changes, suggesting this data is unreliable for interpreting market value. During this time (i.e. 1970's) the fishery in California was transitioning from commercially wild-caught abalone to farmed, and the wild-caught fishery was becoming largely recreational. The menu data continues along the same trend into the late 1980s and 2016.

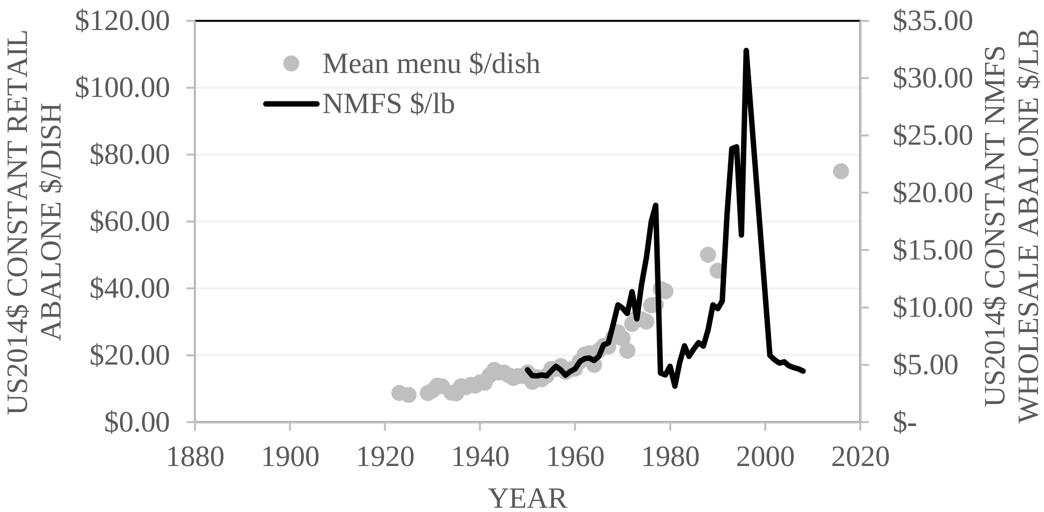


Figure 3-7. *Annual average US2014$ inflation adjusted $/dish for Abalone featured on US West Coast menus compared to NMFS US2014$ inflation adjusted $/lb for Abalone species.* The two datasets are compared on different scales to show the consistency of retail menu prices with wholesale NMFS prices. In effect, the NMFS dataset has been extended back an additional 30 years with the menu prices. Abalone did not become a popular seafood item until after the Panama-Pacific International Exposition in 1915 (p-value <0.01).

Abalone became a commercially valuable species following the Panama-Pacific International Exposition in 1915 when a favored preparation method was developed for western tastes (Jones 2008). Diving for abalone became a popular commercial and recreational fishery during the 1950s and 1960s, with thousands being taken from the coast of California annually (Anderson 2009). Between the years of 1950-1970, 4.4 million pounds of abalone had been removed by commercial divers alone. This, combined with consumer demand, explains the increase experienced during these years for the NMFS and menu data (Figure 3-7). Environmental stressors also contributed to their population reduction; however, because of the severe harvesting pressures, southern California closed sport and commercial abalone diving in 1997.

Although their stocks nearly reached local extinction, consumer demand did not, and this led to the development of successful Abalone Mariculture Farms in the 1980s (Anderson 2009). The development of these farms largely explains the discrepancy between retail menu prices and the NMFS wholesale prices beginning in the 1980s (Figure 3-7). Menu retail prices retained their values as consumers still demanded the abalone and they were supplied by the new aquaculture farms. The NMFS data exhibits a drastic decline in prices and production in the 1980s, inconsistent with menus, as the commercial fishery for wild stocks was greatly reduced by the introduction of successful mariculture practices.

Oysters were by far the largest dataset we have, with approximately 1,200 entries, though these were extremely variable. The most useful prices were the raw preparation, therefore all other preparations were excluded from the final analysis. Oysters were categorized and filtered according to their specific type, revealing four kinds: Toke Points, Californian, Eastern Blue Points, and Olympia Oysters. All prices were normalized to price per oyster ($/oyster), then annual averaged and overlaid with NMFS Eastern Blue Point Oysters (Figure 3-8). NMFS reports oyster commercial catches as the wholesale price per pound of oyster meat. The National Oceanic and Atmospheric Administration (NOAA) provides conversion factors to determine the relationship of oyster meat to the whole oyster. For Eastern Blue Point oysters the conversion factor is 15.08 (NOAA 1990). We used this to convert NMFS $/lb of oysters to $/oyster to be more consistent with menu data. Each type of oyster is represented in Figure 3-8 with a different color. Oyster prices followed the inflation rate until the early-1950s where they experienced nearly a 2.5-fold increase (Figure 3-8).

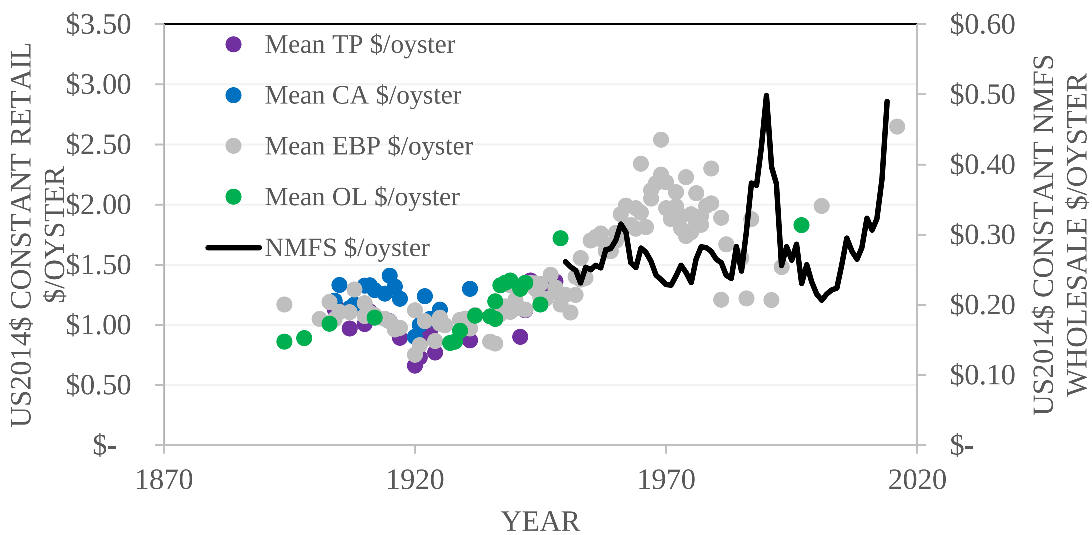


Figure 3-8. *Annual average US2014$ inflation adjusted $/oyster for all oysters featured on US West Coast menus compared to NMFS US2014$ inflation adjusted $/lb for Eastern oysters.* The two datasets are compared on different scales to show the consistency of retail menu prices with wholesale NMFS prices. In effect, the NMFS dataset has been extended back an additional 60 years with the menu prices (p-value <0.01). ***Note**: Each species of oysters were normalized to $/oyster on the menu to be more consistent with NMFS data. They are represented with different colors to show the variation of species featured.
***Legend:** TP – Toke point oysters; CA – California oysters; EBP – Eastern Blue point oysters; OL – Olympia oysters.

It can be seen in the retail oyster prices that California (1920s), Toke Points (1940s), and Olympia Oysters (1950s) stopped appearing on restaurant menus, while the Eastern Blue Points continued after the 1950s. There are two species of oysters in the US that have the greatest commercial value – Eastern oyster (*Crassostrea virginica*) and Olympia oyster (*Ostreola conchapila*), with the former being the most important and explaining their continuance on the menus, while the others fell out of favor (MacKenzie 1996). Through much of the 1800s oysters were only afforded by the wealthy, mostly attributed to insufficient capture productions. With increased oyster harvests from enhancement of gear type, the prices dropped, and oysters became considered a poor man's food. Prices further declined from 1900 to reach their lowest prices during the early 1920s, after which inflation-adjusted prices increased 3-fold by 1970. This pattern supports the notion that they were not an expensive seafood item in the early 20th century (Figure 3-8). The oyster industry underwent three "dark ages" whereby consumer demand decreased which can be supported by fluctuations shown within the menu data (MacKenzie 1996).

The first decline or "dark age" occurred in the early 1900s when the US developed a growing concern over sanitation, often termed in the industry as the "pure food hysteria" (MacKenzie 1996). This lead to enhanced regulations on packaging and shipping of oysters, which in turn lead to decreased demand for oysters and increased production prices. Another shortfall in the industry occurred during the early 1920s with the typhoid scare – people had become ill and died of typhoid after eating oysters (MacKenzie 1996) (Figure 3-8). The final detriment to the oyster industry occurred in the late 1950s, with the

Multinucleated Sphere Unknown (MSX) parasite that began killing huge quantities of oyster populations (MacKenzie 1996). This may help to explain the discrepancy in oyster retail and NMFS prices seen in Figure 3-8. Other species featured in this group are Scallops, Squid, and Mussels.

Invertebrates

There were a total of four invertebrate species included in this category. We present Crab (*Metacarcinus magister*) as our representative species as it was the most comprehensive and locally caught of the four. Crab was filtered according to the type featured on the menu (i.e. Dungeness, Cracked, Deviled, Alaskan, and Legs). Alaskan crab prices were omitted because they were much higher than all the other types, and represent a species not native to the study area. They were further filtered by preparation style, whereby, cocktails, chowders, and gumbos were omitted because the prices were invariably lower. Prices were normalized to whole cracked crab to be consistent with NMFS Dungeness crab data (Figure 3-9). Crab followed the inflation rate until the early-1960s, where it experienced nearly a 2-fold increase. Menu data is relatively consistent with NMFS data, however, it does not show the same cyclical price variability. In effect, the NMFS dataset has been extended for an additional 50 years. The other species featured in this category are Lobster, Prawn, and Shrimp.

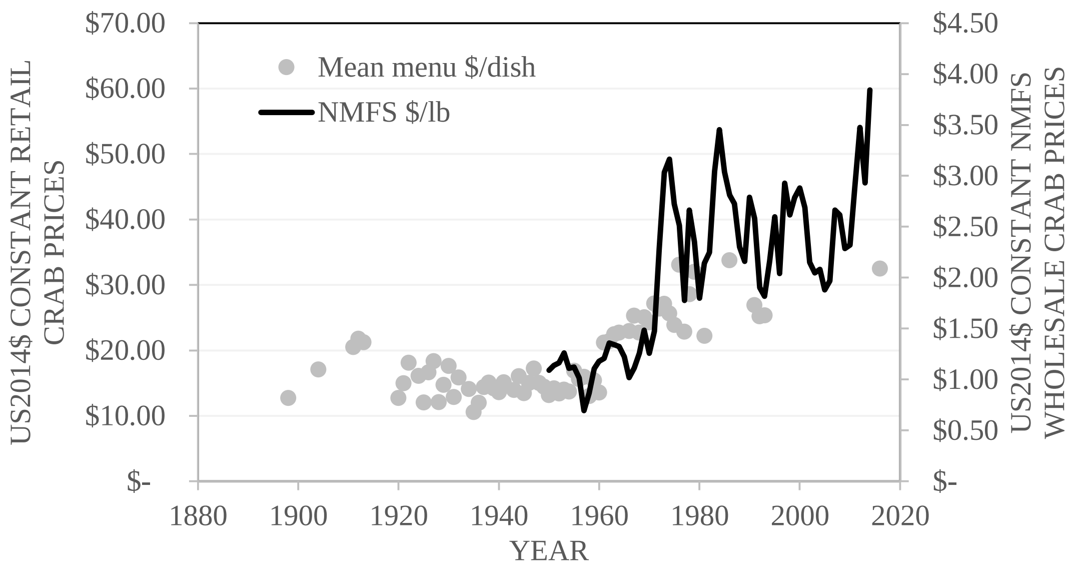


Figure 3-9. *Annual average US2014$ inflation adjusted $/dish for crabs featured on US West Coast Menus compared to NMFS US2014$ inflation adjusted $/lb for Dungeness crabs.* Crab prices were normalized to whole cracked crab servings. The two datasets are compared on different scales to show the consistency of retail menu prices with wholesale NMFS prices. In effect, the NMFS dataset has been extended back an additional 60 years with the menu prices (p-value <0.01).

Demersal fishes

A total of ten species were categorized into this group, but here we present two, Sand dabs (*Citharichthys sordidus*) and Rex Sole (*Glyptocephalus zachirus*), as they were featured on most menus. They provide the most robust dataset of all the demersal species, with an entry for nearly every year since 1904. Sand dab prices were normalized to prices featured on the most common menu, Fisherman's Grotto, as this provided the most comprehensive menu dataset. These prices were annual averaged and then overlaid with NMFS data (Figure 3-10). Over a 25 year period, 1950-1975, Sand dab prices increased nearly 3-fold.

Menu prices corresponded with NMFS data 1950-1975, but deviated until the late-1980s to early-1990s. Although discrepancy between the retail and wholesale data exists, the consistency of the menu price trend suggests Sand dabs are still being demanded by consumers and their supply is effectively supporting that. In effect the NMFS dataset has been extended for an additional 50 years.

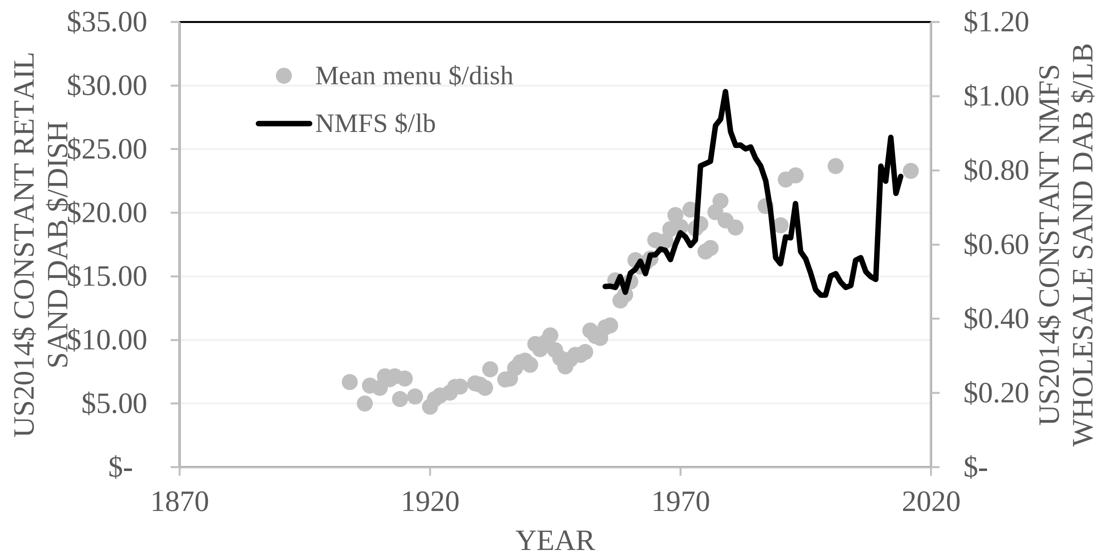


Figure 3-10. *Annual average US2014$ inflation adjusted $/dish for Sand dabs featured on US West Coast menus compared to NMFS US2014$ inflation adjusted $/lb for Sand dabs.* Sand dab prices were normalized to dishes served at Fisherman's Grotto. The two datasets are compared on different scales to show the consistency of retail menu prices with wholesale NMFS prices. In effect, the NMFS dataset has been extended back an additional 50 years with the menu prices (p-value <0.01).

Rex Sole followed a similar trend as Sand dab, which can be expected as they are represented in the same category of fishes, both being dorsal-ventrally flattened fish. Rex Sole prices were normalized to those featured on the most common menu, Fisherman's Grotto. These prices were annual averaged and overlaid with the NMFS dataset (Figure

3-11). Over a 35 year period, 1945-1980, Rex Sole prices increased nearly 3-fold as well. Menu prices corresponded with NMFS data 1950-1975, but deviated until the late-1980s to early-1990s. In effect the NMFS dataset has been extended for an additional 50 years.

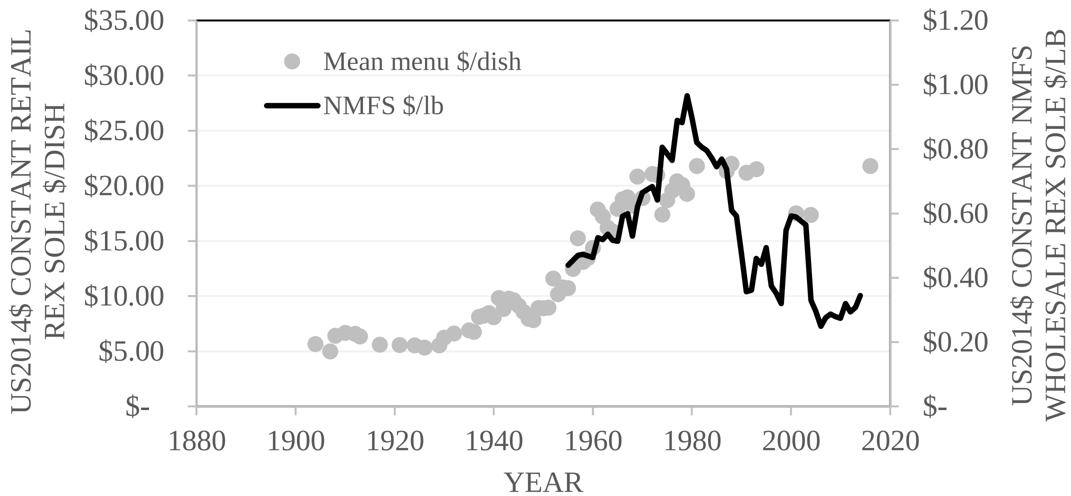


Figure 3-11. *Annual average US2014$ inflation adjusted $/dish for Rex Sole featured on US West Coast menus compared to NMFS US2014$ inflation adjusted $/lb for Rex Sole.* All menu prices were normalized to prices featured on Fisherman's Grotto menus. The two datasets are compared on different scales to show the consistency of retail menu prices with wholesale NMFS prices. In effect, the NMFS dataset has been extended back an additional 50 years with the menu prices (p-value <0.01).

Other species classified in this category were Flounder, Halibut, Sculpin, Sole, Sturgeon, Haddock, Cod, and Turbot.

Small pelagic fish

There were a total of six species classified in the small pelagic fish category, but here we present one, Mackerel (*Trachurus symmetricus*). Mackerel prices were annual averaged and overlaid with NMFS data for Jack mackerel harvested on the Pacific coast (Figure 3-

12). We chose Pacific Jack Mackerel because they are a small species of mackerel, consistent with what we suspect were served in restaurants. Mackerel prices nearly followed the inflation-rate through their exploitation suggesting their supply broadly met the consumer demand. These prices are similar to those presented by the NMFS data (Figure 3-12).

Mackerel are not present on menus after the late 1960s, likely due to taste change of consumers. In early onsets of fishery exploitations, fishermen were limited to sustenance fishing in coastal waters relatively close to shore (Pauly and Watson 2005). This limited their harvesting to species that lived close to shore; however, with industrialization of fishing fleets, fishermen were able to travel further off-shore, allowing for capture of more favorable fish. We assume that Mackerel were no longer desired by consumers as industrialized fishing introduced new species, and therefore, were no longer targeted by fishermen or served in restaurants. The NMFS wholesale $/lb continued to decrease, as well as the commercial harvest (Appendix A). With a decrease in supply, a decrease in wholesale $/lb, and no feature on menus, we can assume the consumer demand was low, if existent. This species likely transitioned from a food fish to be used in fishery products such as fish oil and fish meal. Following 2010, NMFS commercial landing decreased considerably.

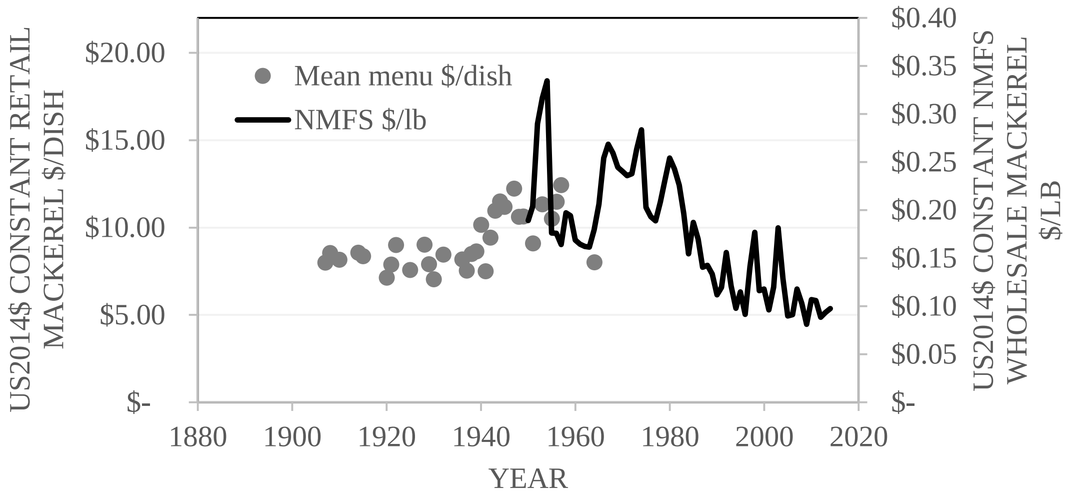


Figure 3-12. *Annual average US2014$ inflation adjusted $/dish for Mackerel featured on US West Coast menus compared to NMFS US2014$ inflation adjusted $/lb for Pacific Jack Mackerel.* The two datasets are compared on different scales to show the consistency of retail menu prices with wholesale NMFS prices. A single NMFS data point for 2005 (US$0.40/lb) was omitted from the final figure as it was anonymously high and was not consistent with prices shown in years prior to or after this date. We include it here in the figure caption for reference. In effect, the NMFS dataset has been extended back an additional 50 years with the menu prices (p-value <0.01).

The other species featured in this category are Shad, Pompano, Anchovies, Sardines, and Herring.

Medium pelagic fishes

There were seven species categorized as medium pelagic fishes found on the West Coast menus. We chose to use Salmon (*Oncorhynchus tshawytscha*) and Sea Bass (*Centropristis striata*) as our representative species for this group. Salmon prices were refined according to preparation style, such that poached, steamed, and smoked were omitted as these prices were much lower than all other preparations. Prices were normalized to those featured on Fisherman's Grotto as this was our most comprehensive menu dataset. These prices were then annual averaged and overlaid with the NMFS dataset (Figure 3-13). Salmon prices experienced nearly a 5-fold increase over a 60 year period, owing greatly to their consumer demand.

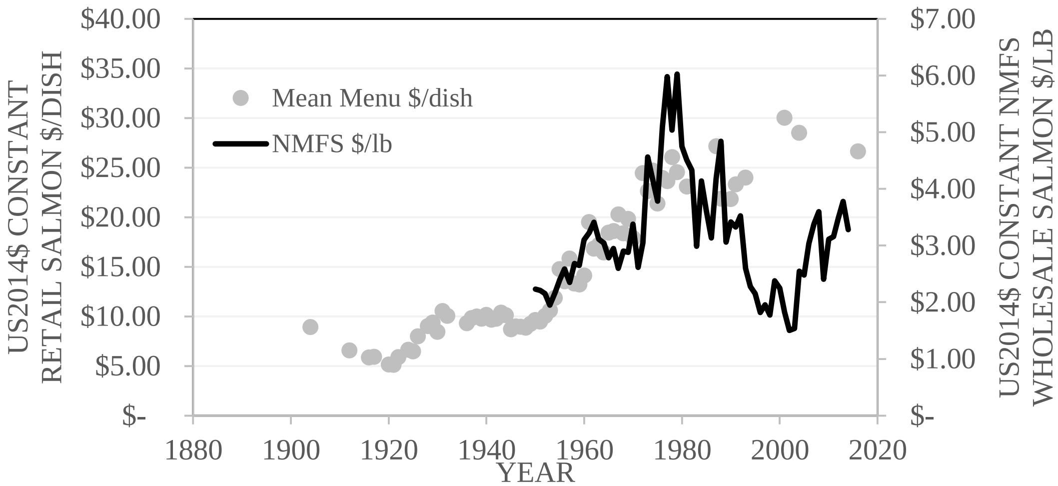


Figure 3-13. *Annual average US2014$ inflation adjusted $/dish for salmon featured on US West Coast menus compared to NMFS US2014$ inflation adjusted $/lb for Chinook salmon.* Salmon prices were normalized to dishes served at Fisherman's Grotto. The two datasets are compared on different scales to show the consistency of retail menu prices with wholesale NMFS prices. In effect, the NMFS dataset has been extended back an additional 50 years with the menu prices (p-value <0.01).

The salmon fishery was markedly one of the most important fisheries to the West Coast of the US (Anonymous 1901). So much so, that by the early 1900s, seasonal regulations were being implemented to allow for successful spawning as salmon were being harvested before they could undergo such events (Anonymous 1894). There were noticeable declines in their populations in the 1870s (Anonymous 1877), which continued to worsen with the development of salmon canneries (Anonymous 1894). In order for the supply to continue meeting the demand, salmon hatcheries were developed along the Atlantic Coast in the late 1890s to provide salmon eggs and juveniles for release (Anonymous 1896). This continued consumer-driven demand of salmon can be shown in the respective NMFS and menu data (Figure 3-13).

Salmon aquaculture production began in the 1980s (Appendix A); the NMFS wholesale $/lb and commercial catch began declining during this time. This is counterintuitive, as it would seem if wild stocks were declining, and the demand remained the same, the wholesale $/lb would increase. However, this is not the relationship reflected in the NMFS data. The menu prices, on the other hand, continued to increase into the early 2000s, suggesting consumer demand remained high. This discrepancy in NMFS and menu data is likely because the consumer demand was now largely being met with aquaculture raised fish, rather than wild stock.

The catch stays relatively the same from 1960-1980, therefore the supply is the same, but the price continues to rise on menus – it can be assumed the demand was increasing (Appendix A). This increase in demand eventually lead to the need for aquaculture of this species. In this case, the NMFS statistics may not be the most representative data as it does not reflect the consumer demand for the particular species. Similar trends were seen with Abalone (Figure 3-6).

Sea Bass were represented by several different species (Pacific Sea Bass, Deep Sea Bass, Chilean Sea Bass, Striped Sea Bass, and Sea Bass), with the majority being Sea Bass. Deep Sea Bass prices were much higher than the Pacific Sea Bass, therefore, were omitted from the final dataset. Black Sea Bass, another medium pelagic fish, only had two entries, but were added to the original Sea Bass dataset to be normalized. These prices were similar to those exhibited by the Pacific Sea Bass. All prices were normalized to those featured on Fisherman's Grotto menus, as this was our most comprehensive menu dataset and remains consistent with other species (Figure 3-14). There is discrepancy between the menu and NMFS dataset in 1950; however, it begins to follow a similar pattern into the 1960s and forward. Sea Bass menu prices began rising faster than the inflation rate in 1950, with nearly a 3-fold increase over 40 years.

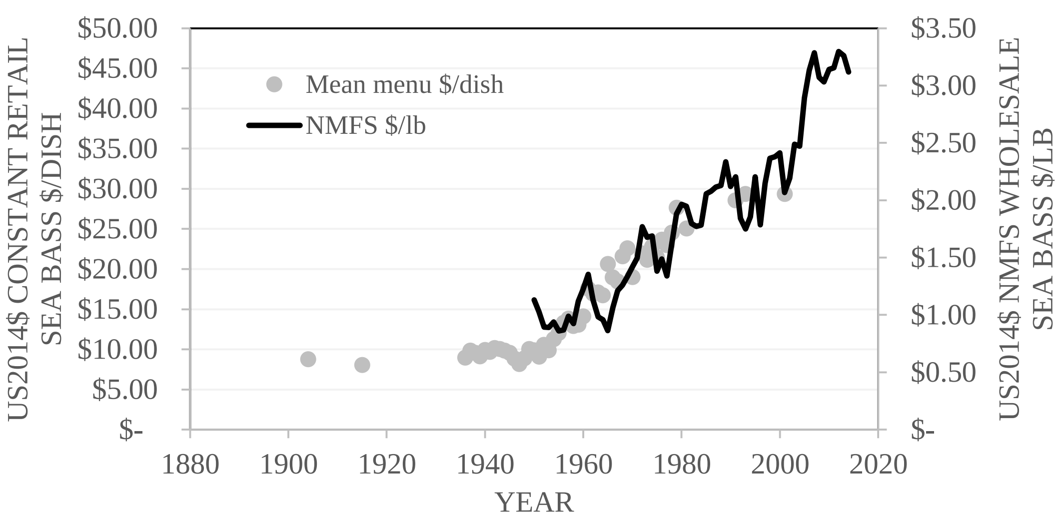


Figure 3-14. *Annual average US2014$ inflation adjusted $/dish for Seabass featured on US West Coast menus compared to NMFS US2014$ inflation adjusted $/lb for Black Seabass.* Menu prices are normalized to Fisherman's Grotto prices. The two datasets are compared on different scales to show the consistency of retail menu prices with wholesale NMFS prices. In effect, the NMFS dataset has been extended back an additional 50 years with the menu prices (p-value <0.05).

The other species featured in this category are Rock bass, Corvina, Blue fish, Striped bass, and Red Snapper.

Large pelagic fishes

There were a total of eight large pelagic species found on the West Coast menus. Here we present our most representative, Swordfish (*Xiphias gladius*) and Barracuda (*Sphyraena argentea*). Prices were annual averaged and overlaid with NMFS data (Figure 3-14). Swordfish NMFS prices followed the inflation rate from 1950-1970, then experienced a 4-fold increase during their exploitation. Swordfish retail prices, on the other hand, appear to continually increase faster than the inflation rate following 1940. There is decoupling between the NMFS data and menu data during the 2000's likely due to a growing health concern among patrons.

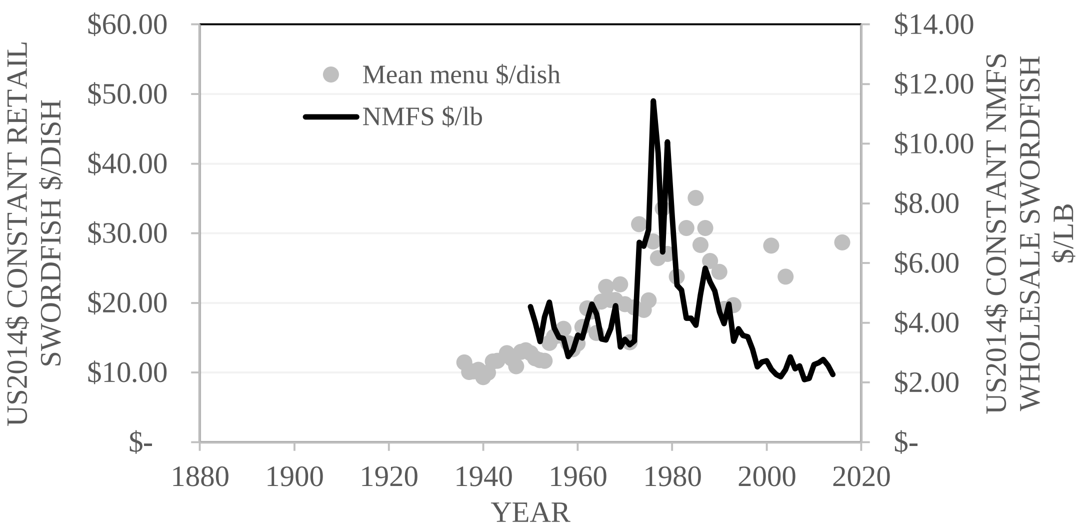


Figure 3-15. *Annual average US2014$ inflation adjusted $/dish for Swordfish featured on US West Coast menus compared to NMFS US2014$ inflation adjusted $/lb for Swordfish.* The two datasets are compared on different scales to show the consistency of retail menu prices with wholesale NMFS prices. In effect, the NMFS dataset has been extended back an additional 20 years with the menu prices (p-value <0.01).

With a decline in menu prices, we can assume there was a decline in consumer demand for Swordfish. Swordfish is a large pelagic species shown to contain high levels of Mercury – this likely lead to consumers choosing not to eat the fish for health concerns. The NMFS commercial landings for Swordfish began declining in the early 1990s (Appendix A), the same is seen in the respective wholesale $/lb and menu retail $/dish. Intuitively, a decrease in landings would lead to an increase in $/lb if demand remained; however, this is not the case for Swordfish. With declining supply, the wholesale and retail prices also decline, suggesting a diminishing consumer demand.

Barracuda prices were normalized to Fisherman's Grotto menu prices, as this was the most robust dataset, therefore, we can be confident the adjustment factors for subsequent years are representative of the species. Barracuda experienced nearly a 2-fold increase in retail prices from 1950 to the late-1960s (Figure 3-16).

We used two different NMFS datasets for comparison: Barracuda landed on the Pacific Coast and Pacific Barracuda landings. NMFS Barracuda commercial landings stopped in 1980 and began again in 2003. Interestingly, the Pacific Barracuda commercial landings began in 1981. It appears that as the NMFS Barracuda fishery collapsed, it was replaced with the Pacific Barracuda fishery (Appendix A). The NMFS Barracuda fishery never seemed to recover; and shortly after it's beginning, the Pacific Barracuda fishery also failed with no regain in commercial landings (1997).

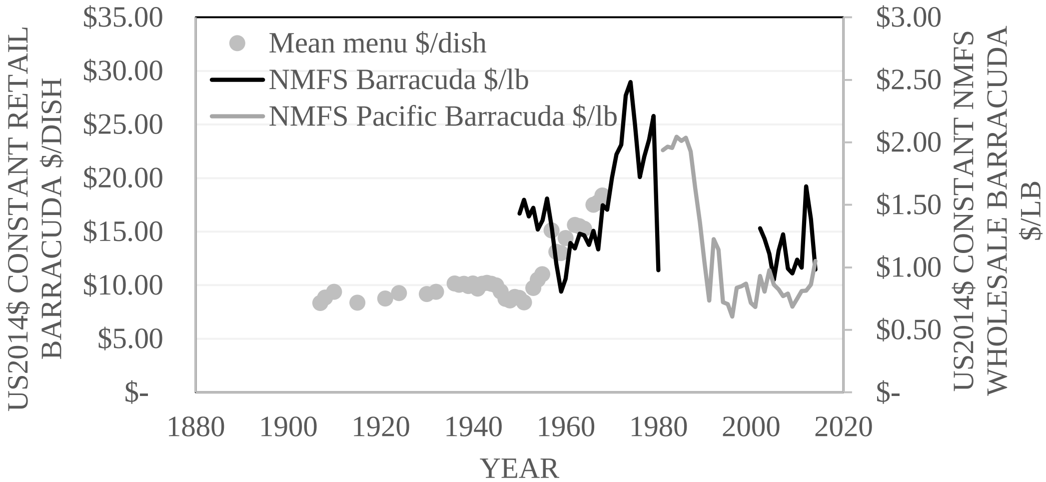


Figure 3-16. *Annual average US2014$ inflation adjusted $/dish for Barracuda featured on US West Coast menus compared to NMFS US2014$ inflation adjusted $/lb for Barracuda and Pacific Barracuda.* Barracuda menu prices were normalized to Fisherman's Grotto featured prices. The two datasets are compared on different scales to show the consistency of retail menu prices with wholesale NMFS prices. In effect, the NMFS dataset has been extended back an additional 70 years with the menu prices (p-value <0.01).

Changes in the popularity of fish can be seen through the menus that may otherwise not be reflected in the NMFS dataset, such as with Barracuda. In early menus, it was a popular seafood item, and the wild stocks were thought to be plentiful (Anonymous 1892a). No menu data extends past the 1970s. They were heavily targeted by purse seine fisheries in the 1900s (Walford 1932) which greatly decreased wild barracuda populations by the early 1940s (MBA 2016). Barracuda fell out of favor with consumers because of impeding health concerns (MBA 2016). The growing concern of ciguatera fish poisoning, often found in barracuda, contributed to much of their disappearance on menus (Recks and Smith 2014, FAO 2004).

There is a discrepancy between the menu data and NMFS wholesale $/lb in the early 1950s, which may be attributed to the collection of the NMFS data. Consumer demand was increasing in the 1950s – 1960s, a time when the barracuda fishery experienced the greatest commercial catch (lbs). By 1970, the Barracuda commercial catch had reduced 5-fold, while the retail menu prices continued to increase (Appendix A, Figure 3-16). This is a strong indication of consumer-driven demand – supply was decreasing as retail prices and wholesale prices were increasing. Although they seemed to be growing in popularity, they abruptly disappeared from menus, attributed to growing health concerns from consumers.

The other species in this category are Yellowtail amberjack, Mahi Mahi, Shark, Totoaba, Tuna, and Wahoo.

Dickey-Fuller statistics

The results of the Dickey-Fuller statistics test are summarized in Table 3-1 for each of the species presented in this section. If the individual series did not exhibit non-stationary characteristics (i.e. t-statistics > -2.86), then they did not qualify to test for co-integration, which resulted in blank spaces for the co-integration results (Table 3-1). The t-statistic outputs were compared to 5% critical values in both stationarity and co-integration tests. For the test for stationarity, the 5% critical value was -2.86 (Wooldridge 2016, p. 575), while for the 5% critical value for the co-integration tests was -3.34 (Wooldridge 2016, p. 581). We can ignore the p-values for these tests because those are calculated using a t-distribution chart, while Dickey and Fuller found that the tests for stationarity and co-integration are calculated from a τ-distribution chart. Therefore, we compare the t-statistics with these critical values, as the generated p-values are irrelevant (Wooldridge 2016).

Table 3-1. *Results of the Dickey-Fuller Statistics tests for the representative species of the US West Coast.* If the data series did not show non-stationarity with the first test, they did not qualify to test for co-integration, therefore, some blanks exist for the co-integration results section. These results show the t-statistics values instead of p-values, as these tests are compared to τ-distribution values instead of t-distribution (Wooldridge 2016). The 5% critical value for the test for stationarity is -2.86, while the 5% critical value for the test for co-integration is -3.34 (Wooldridge 2016). An intercept exists for each of these values but were not included in this table as it was unnecessary information to report.

	Test for Stationarity				***Test for Co-integration***		
	Menu Statistics		*NMFS Statistics*		*Regression of Residuals (NMFS v Menu)*		
Δ in dependent	**t-statistics**	**Stationary (Y/N)**	**t-statistics**	**Stationary (Y/N)**	**Δ in dependent residuals**	**t-statistics**	**Co-integrated (Y/N)**
Abalone	2.787	Y	-3.423	Y	Abalone		
Oysters	-1.255	N	-1.174	N	Oysters	-1.3	N
Clam	-3.191	Y	-4.75	Y	Clam		
Crab	-2.394	N	-1.716	N	Crab	-2.135	N
Rex Sole	-0.772	N	-1.262	N	Rex Sole	-2.148	N
Sand dab	0.088	N	-1.813	N	Sand dab	-1.805	N
Mackerel	-2.763	N	-3.976	Y	Mackerel		
Seabass	0.223	N	-0.441	N	Seabass	-3.405	Y
Salmon	-0.673	N	-2.666	N	Salmon	-2.711	N
Swordfish	-2.111	N	-2.441	N	Swordfish	-2.411	N
Barracuda	0.358	N	-2.335	N	Barracuda	-2.162	N

Only three species were unable to run the test for co-integration (i.e. Abalone, Clam, and Mackerel), while only one species (i.e. Seabass) showed they were co-integrated. We are attributing this to several different factors: 1) possible problems within the NMFS data - more commercially important species will likely show better results as more effort is put into those particular statistics; 2) there is no way to verify the species that are being served on the menu as it is only labelled by a common name (e.g. Swordfish, Rex Sole, Flounder), while the NMFS specifies the particular species (e.g. Pacific Swordfish, Rex Sole, Southern Flounder); 3) there may also be discrepancies with the menu data because we cannot determine if the species being served is caught locally unless it is specified (rarely occurs); 4) the menu dataset is not likely robust enough in this region to run an effective test; and 5) the increase in reliance of aquaculture rather than wild-caught populations. There are other Dickey-Fuller tests that we can use but they are beyond the scope of this thesis; however, since we are going to do similar studies for the Northeast Coast fisheries, we will likely continue running additional tests on the two datasets in order to compare the results from the West Coast to the East Coast.

Trophic-level assessment

The most straightforward way to describe an ecosystem with fisheries is in terms of feeding interactions among species (Pauly et al. 2002). We modified this approach according to the menu dataset, such that, we explained the same concept using inflation adjusted prices of featured seafood items. Categorizing the species afforded a virtual trophic assessment, as the trophic levels provided by Fishbase (www.fishbase.org) were too similar to show any confident difference. As these trophic levels are based on previous gut content analysis studies (Branch et al. 2010, Pauly and Watson 2005, Froese and Pauly

2000), they are more effective when determining species-species relationships, whereas for our approach it was more important to classify them according to consumer preference which relates to size and habitat location.

It is important to note that these prices are inflation-adjusted, therefore, any deviation from a horizontal line will reflect their respective relationship to the inflation rate. If prices are increasing relative to the inflation-rate, then those prices are rising faster – an indicator of consumer-driven demand. Consequently, if the price trends show a decrease relative to the inflation-rate, this indicates the prices are rising slower than the inflation rate, implying a lack of consumer-demand (in the simplest case). Each of the representative species closely followed the inflation rate at the beginning of their exploitation (nominally 1900-1930), but soon experienced price increases that rose faster than the inflation rate. We wanted to determine if this would be exhibited on a trophic-level as well – which is presented in Figure 3-17.

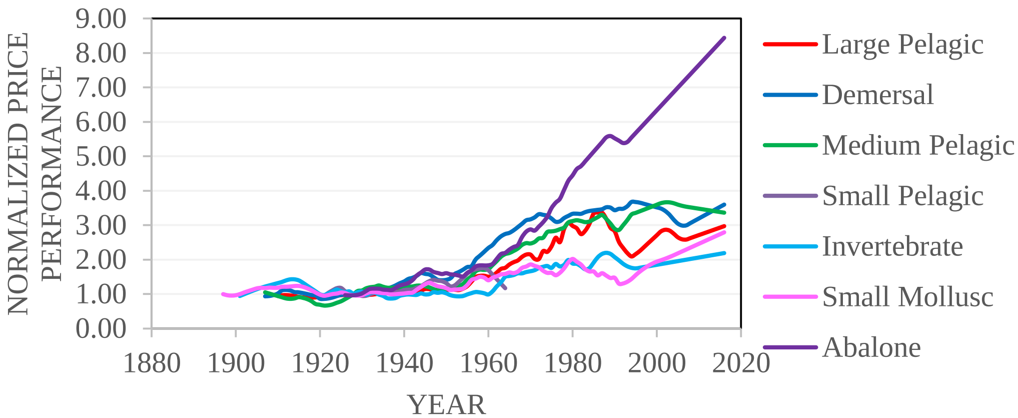


Figure 3-17. *Boxcar average of a trophic-level assessment using fishery retail prices to compare the rate of inflation between the different species categories.* The square box indicates the section of this figure that is presented in the next one in order to show a clearer representation of the trends the retail prices experienced as they began rising faster than the inflation rate. Each species has a constant value (nominally 1900-1930) where prices tracked the inflation rate, so the prices were normalized to this period of time. This allows for all prices to be shown relative to their constant (i.e. inflation-adjusted) price period.

This is the first trophic-level assessment of fishery retail prices attempted, and therefore, we wanted to test if we could show the 'Eating down the food web' phenomenon with this type of analysis. For the menu data, there exist data gaps as these were ephemeral items, therefore, we interpolated the data for years which prices were missing. This interpolation allowed for a complete dataset from approximately 1900 to 2016. We normalized these prices to the region (nominally 1900-1930) in which the inflation-adjusted prices followed the inflation rate. We then used a boxcar average for this time-series data to create a smooth curve to show the long-term price trends, to minimize short-term fluctuations that would otherwise make interpretations more difficult. It is clear that the prices for all of the species categories are rising faster than the inflation rate prior to 1950 (Figure 3-17); however, it is difficult to see the rate of this exploitation on the time-series scale shown.

We provided an additional figure focusing on the years 1930-1960 as this is the time in which we see the changes in price trends begin to deviate from the inflation-rate (Figure 3-18).

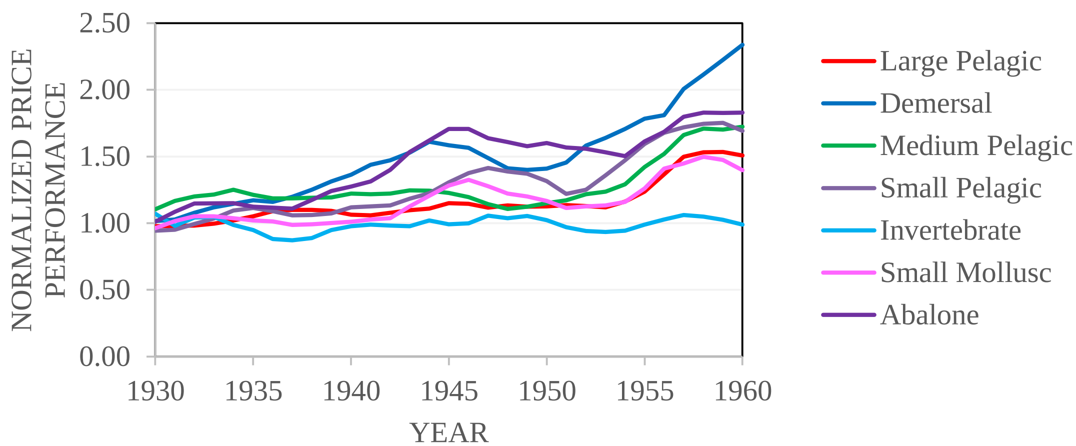


Figure 3-18. *Boxcar average of trophic-level assessment using fishery retail prices to compare the rate of inflation between different species categories with emphasis from 1930-1960 when all the categories began rising faster than the inflation-rate.* This was presented to show a clearer representation of the retail price trends experienced by the different categories of species. Each species has a constant value (nominally 1900-1930) where prices tracked the inflation rate, so the prices were normalized to this period of time. This allows for all prices to be shown relative to their constant (i.e. inflation-adjusted) price period.

Figure 3-18 presents a clearer representation of the normalized performance of inflation-adjusted prices for each of the species categories. The baseline value for each of the species is 1.00, therefore we wanted to see how quickly the prices rose 50%, 100%, and 200% above the inflation rate. The trend experienced by each of the species categories occurs at different times and rates. As can be seen in Figure 3-17, Abalone experiences an 8-fold increase in the price trends, while large pelagic fishes only exhibit a 2-fold increase. We further investigated these trends to determine if an 'Eating down the marine food web' scenario could be demonstrated using these retail fish prices relative to the percent (i.e. 50%, 100%, 200%) increase and the years in which these percentages increased above the baseline value (i.e. inflation-rate).

Conclusion

Fisheries have been impacted for much longer than originally perceived, with no government database available to accurately indicate these previous exploitations. Efforts to understand the consumption of fisheries is even more limited (Van Houtan et al. 2013), but this may prove as one of the most viable components to fisheries management, as consumer demand drives harvests of targeted fisheries. Restaurant menus document seafood consumption and their respective prices, offering the ability to track exploitation of wild populations and distinguish the value of different species in the past (Van Houtan et al. 2013). Menus do not provide information about the rises or declines experienced by fisheries, therefore, contemporary literature must also accompany menu analyses for these explanations. Recent digitization of such resources has made it an effective tool in discovering market trends, legislation, and potential population fluctuations.

Fisheries on the US West Coast developed much later than those on the New England and Atlantic Coast; however, still proved to contribute greatly to the overall US seafood production. Halibut, Salmon, and flounders constituted the greatest number of landings in the region; however, the variety of marketable fish was very great (Anonymous 1892a).

Retail prices varied on menus for the different flatfish as the best were sole (Anonymous 1892a).

It is important to note for this study that data reported by the NMFS accounts for *wild-caught* fish production and does not account for *aquaculture* production. Marine aquaculture was a response to growing fish demand and dwindling wild fish stocks in the 1980s (FAO 2014). The US marine aquaculture contributes to 1.5% of global aquaculture seafood production, but the country is among the top consumers of seafood products. The US is the leading country in seafood imports, with 81% of the seafood consumed imported, with half of them being farmed imports (FAO 2014). The current global wild fish harvest is 95 million tons, while aquaculture fish production contributes 60 million tons (FAO 2014). The growing contribution of aquaculture – the greatest in the US being oysters, clams, mussels, salmon, and shrimp – supplies the consistent demand of consumers. Unlike early exploitation (pre-1975), present retail fish prices do not likely reflect the value of the fishery as the demand is largely being met by an aquaculture grown fish rather than a wild harvested fish. We have examples from the West Coast that exhibit this, including: Salmon and Abalone.

For species such as Salmon and Abalone, the NMFS data may not accurately represent their consumer value. The menus can be used to track price fluctuations, as well as, consumer preferences by their respective values and trends. These menu prices do not necessarily reflect wild populations, which is more likely to be true for present fisheries, but still show fish popularity. For consumer's, with regards to the NMFS data, wholesale fish prices are as cheap now as they were in the 1950s because although wild fish populations are being depleted, their demands are being met with farmed fish. For species with aquaculture production replacing much of the wild caught production, it may be beneficial to confide in retail fish prices to determine real market trends.

We conducted the first trophic-level assessment using fishery retail prices. Our null hypothesis was that all of the species would exhibit the same inflation-adjusted retail price changes; with the alternative hypothesis being that they would experience these price trends at different rates and times. We hypothesized that the prices for the larger, more consumer-desirable species (i.e. large pelagic fish) would rise faster than the inflation-rate earlier than smaller, less-desired species (i.e. invertebrates) – showing an 'Eating down the food web' scenario. Table 3-2 outlines the order we observed, as well as, the respective years the prices rose 50%, 100%, and 200% above the inflation-rate.

Table 3-2. *Results for the boxcar averaged trophic-level assessment using fishery retail prices.* The table provides our anticipated sequence of the species categories with respect to their relationship with the inflation-rate; the resulted sequence; and the respective years in which the retail fish prices reach 50%, 100%, and 200% above their baseline value. Each species has a constant, or baseline, value (nominally 1900-1930) where prices tracked the inflation rate, so the prices were normalized to this period of time. This allows for all prices to be shown relative to their constant (i.e. inflation-adjusted) price period. If no value is entered it signifies that species category never reached the percentage indicated.

	% above baseline value		
Actual Sequence	50%	100%	200%
Demersal	1943	1957	1968
Abalone	1943	1962	1973
Small Pelagic	1955		
Medium Pelagic	1956	1963	1979
Large Pelagic	1957	1968	1979
Small Mollusc	1959	1980	
Invertebrate	1964	1986	

As this study is the first of its kind, we wanted to test if it was a viable approach in determining trophic-level alterations, strongly mediated by consumer-driven demand. The data does not clearly show a 'shifting baseline' scenario for the Pacific Coast of the United States through this type of analyses; however, it may suggest it is much more complex for consumer preference vs. fishing effort (previously studied). 'Eating down the food web' scenarios may not be equivalent to the trends experienced in 'Fishing down the food web' scenarios, as we would expect to see fish from top trophic levels experiencing higher prices early, followed by increasing prices of lower trophic level species as the larger fish are being depleted – however this is not the trend we see with this analysis.

This study shows the need for more detailed analyses for fishery prices prior to 1950, as most of the species prices rise faster than the inflation-rate before this time. A good example of this is Sea bass (Figure 3-14) as we are missing data from 1915-1935. Although it seems that the prices would follow the inflation rate as the prices in the early 1900s are relatively the same as prices in the 1940s, this is still unknown. A similar study is being done for the Northeast Coast of the US in order to compare the behavior of the West Coast species (this study) to those exhibited by the Northeast Coast (Jones in progress) species. This will afford the ability to determine if the ecosystems demonstrate different trends or if they are relatively similar.

Our study has contributed conceptual and methodological approaches to the comprehension of understanding historical human impacts to the marine ecosystem. It can be seen with this study that the best years to compare NMFS data and the menu retail prices are from 1950 – 1970, as these years represent wild-caught fish species. We have nominally extended the NMFS dataset an additional 50 years into the past – an important component when determining their consumer-driven demand and interpreting the rate at which different species' retail prices rose faster than the inflation rate. Overall it provides a more detailed examination of the exploitation of marine fisheries prior to the establishment of government databases (e.g. NMFS) that are utilized today for fisheries management practices, as well as, provides an interpretation of these exploitations from a consumer-preference point of view.

Understanding the effects of consumer driven demand is a new sector of fisheries ecology, yet it has shown with this study to be effective in determining market behavior of commercially valuable species prior to the establishment of government catch statistics. Without this data, exploitation of these species would otherwise be unknown and hinder the understanding of species-ecosystem dynamics. It is unlikely that historical data can be strictly used to predict the fate of fisheries; however, contributing this unexamined data to current management approaches will provide a more robust database for assessing impacts. Overall this will provide a better prediction into the fate of such fisheries, which may aid in the protection of current and future diminishing stocks.

CHAPTER IV

A MODEL FOR CONTROLLING LIONFISH WITH CONSUMERS – A CASE STUDY IN ARUBA

Introduction

Marine ecosystems are a dynamic network complicated by intricate interactions among species, communities, and environments influenced by biotic and abiotic factors. Fisheries further complicate this by exploiting components of the ecosystem and are complex and dynamic in themselves with gear types, fishing strategies, and knowledge (Cochrane 2002). These systems are further complexed by dispersal of fish populations with varying species-specific life history traits that must be considered when structuring management approaches. Fisheries managers have the difficult decision of determining the current situation of fisheries and then forecasting how that particular resource will change in response to management actions implemented with data and recommendations provided to them by scientists (Cochrane 2002).

Fisheries management strategies[2] aim to follow vaguely defined steps dependent on biological, ecological, social, and economic factors. These are described as vaguely designed because they may differ according to location, technical gear, fish species, etc. Fisheries managers must determine fisheries policies which are often guided by broad

[2] Fisheries management strategy is defined by the Food and Agriculture Organization as the overall set of measures implemented by a fisheries management authority(s) to regulate fisheries. These can include technical and biological measures (Cochrane 2002).

information on the type of fisheries; the nature of the resources and ecological context of those resources; social and economic characteristics and the importance of those factors (FAO 1997, Sissenwine & Kirkley 1982). They must also set goals that draw on the historical performances of fisheries including fishery yields, economic and social structure; consider the existing problems and opportunities; and examine the constraints of scientific estimates (FAO 1997).

Scientists are often responsible for estimating the biological (e.g total landings of species per fleet; total fleet effort per annum; length and/or age composition of species caught; total number of discards; length and/or composition of total discards; areas fished) and ecological (e.g. total bycatch on a species basis; length and/or age composition of bycatch; direct and indirect impacts of fishing gear; changes in the structure of critical habitats by non-fishing activities) components important to fisheries management (Cochrane 2002, Sissenwine & Kirkley 1982). Fisheries management strategies are defined in Table 4-1 as described by the Food and Agriculture Organization (2008). As we are including the roles of consumers in our approach, this provides a more holistic approach to fisheries management. Challenges exist when transitioning conventional approaches to a more robust system-wide approach; however, scientists globally have discovered the broadened benefits of Ecosystem-Based Fisheries Management (EBFM) (Dichmont et al. 2008).

Single species stock assessments are the most widely used approach for determining maximum sustainable yields of current fisheries, as they were started in the early 1950s (e.g. NMFS). These concepts and models used for such analyses have evolved since their original creation; however, they still lack in providing adequate assessments of fishery stocks due to four particularly broad problems. Assessment results often ignore or limit the effects of fishing mortality of stock maintenance on the excuse they are not precise enough to restrict fisheries; however, have proven effective on maintain stocks if applied (Pauly et al. 2002, Dayton 1998). Assessment methods have been insufficient in estimating the severity of rapid stock declines and the increasing depensatory impacts of fishing during such declines (Pauly et al. 2002, Walters and Maguire 1996). There has been failure in overall implementation and development of regulatory tactics (Pauly et al. 2002, Perry et al. 1999). Finally, there have been severe violations in the assumptions made about compensatory responses of fisheries in recruitment to spawning size reduction (Pauly et al. 2002, Walters and Kitchell 2001). This can potentially worsen the severity of implications to fisheries management if it leads to alternate stable states of ecosystems (Pauly et al. 2002, Scheffer et al. 2001). Because of these reasons, it has been widely accepted by scientists and fisheries managers that transitioning to an ecosystem-based approach is more comprehensive.

Although these strategies are mostly effective, shortfalls remain in these scientific approaches. They are further complicated when structuring and creating a fishery for an invasive species[3]. A fishery for a non-indigenous species cannot be viewed in the same

[3] An invasive species is defined by the US Department of Agriculture (USDA) as a non-native plant, animal, or pathogen that is introduced into an ecosystem where their presence does or is likely to cause

manner as our current fisheries, such that, we avoid establishing the same restrictions and protections we have on present fisheries. Laws, mandates, acts, and limitations were established in order to protect and maintain commercially and recreationally important fish; however, this is not the approach to take when developing a fishery for an invasive species. The underlying goal for these particular fisheries are to reduce the alien populations to a manageable yield, such that, native fish populations can flourish and fisherman are provided economic sustainability. We have conducted preliminary research in Aruba, and in this chapter we use that data to create and conceptualize a pilot-consumer driven sustainable[4] lionfish fishery model for this region. Aruba is a small island that represents the most southern extent of the lionfish invasion in the Caribbean Sea.

harm (2016). For the purpose of this thesis the terms invasive, non-indigenous, and alien species will be used interchangeably.

[4] For this thesis, the use of sustainable, does not use the definition in terms of perpetuity, but rather refers to removing lionfish below an invasive threshold and maintaining a viable fishery for future continuance.

Table 4-1. *List of conventional fisheries management strategies and considerations with descriptions, potential problems or constraints and assessments that are needed before implementing such strategies (*FAO 2008, Kirkley et al. 2002*).*

	Principle	Description	Problems or Constraints	Assessment Needed
Technical Measure	Gear modifications	Refers to increased selectivity because of gear type.	Gear modifications may lead to increase of by-catch, size-select harvesting, genetic changes in affected populations, and changes in the size of fish growth and maturity.	It is important to consider the survival rate of organisms with the introduction of a gear type and the potential effects to non-target species.
Technical Measure	Gear issues	Refers to indirect effects of using different gear types.	Loss of fishing gear may continue to incidentally capture fish for weeks, months, or years.	This can be limited by using biodegradable materials, installing disabling mechnisms, or quick retrieval processes.
Technical Measure	Spatial and temporal controls	Restrictions imposed to reduce fishing mortality to certain times or seasons, with particul gear, or in particular areas (includes closures).	In areas of shared jurisdiction, there must be collaboration between fishing parties. These can be limited in their effect by merely displacing fishing activity and increasing mortality of fish species in other life stages elsewhere.	A synthesis of important ecosystem elements and evaluation of potential benefits or hazards must be obtained. Species-specific interactions and biology must be assessed and understood prior to implementing restrictions or closures.
Technical Measure	Gear impact to habitats	Refers to the consequential impacts fishing gear may have on the environment.	Fishing gear that contacts the seafloor during fishing operations is likely to produce negative abiotic and biotic impacts.	Precautionary approaches are advised with the use of high-impact fishing methods in critical habitats because the long-term effects of such impacts are difficut to quantify.
Technical Measure	Energy efficiency and pollution	Refers to the encouragement of fishing vessels and production to move to a less impactful form of energy use.	The impact of exhaust gas emmisions of dangerous substance are encouraged to be reduced. Fishing vessels often use fossil fuels for propulasion, operation of fishing gear and preservation and/or processing of their catch.	Optimal energy use can be achieved through improved efficiency of fishing gear and management.
Input (effort) and Output (control) Efforts	Capacity limitation	Seeks to restrict the total size of the fishing fleets, thus reducing both fishing mortality and pressure of decision-makers to allow greater fishing mortality.	Asymmetry among managers and fishers may develop as information is shared between these two groups. This leads to potential serious issues in fisheries management (Kirkley et al. 2002).	Better attention must be paid during management and information collection between managers and fishers. Attempts to better estimate capacity must also be stressed (Kirkley et al. 2002)
Input (effort) and Output (control) Efforts	Effort limitation	Seeks to restrict the fishing activity of fleets and thus reduce fishing mortality. Because it operates on a fleet level, this has the potential to reduce mortality in all species associated with the fishery.	These approaches are difficult and complicated to enforce because of the expense and extensive amount of data required to be successful.	Other methods are more attractive which are not as costly or complicated including restrictions with: closed seasons, license restrictions, monetary measures, property rights, and territorial rights.
Input (effort) and Output (control) Efforts	Catch controls	In the form of catch limitations, catch controls aim to directly reduce fishing mortality of target species. If these are complimented with by-catch controls, they have potential to protect associated species.	This may lead to undesirable outcomes such as high-grading, increase in discards, etc.	It is necessary to implement consistent catch limits across the entire range of target and by-catch species in order to reflect a difference and address the desired success of the ecosystem objective.
Ecosystem Manipulation	**HABITAT MODIFICATION**			
Ecosystem Manipulation	Prevent degredation	Prevent damage, restore habitats where damage has occurred, or create new habitats where it is deemed necessary.	Various types of gear and fishing practices impose threats to the environment whereby the integrity of the habitats that support fishery resources and important ecosystem functions are compromised.	Measures needed for restoration or to prevent degredation: prohibit destructive fishing methods, prohibit intentional cleaning of the seafloor for fishing, and reduce the intensity in some fishing areas to ensure non-target species populations are not reduced to unacceptable levels.
Ecosystem Manipulation	Provide additional habitat	Habitat must be created in areas deficient for desired/target species. This can be done through rehabilitation programmes (re-create physical structure necessary for animals to shelter and forage) or artificial habitats (allow establishment of juvenile recruitment, stock enhancement, and settlement succes).	Achieving some habitat restoration may not provide the full potential of the programmes goals to improve productivity and biodiversity. Artificial habitats have the potential to become navigational hazards, pollute the ecosystem, disrupt the structure and function of the resident ecosystem, or redistribute fish species in a manner that increases the fishing vulnerability.	Decision to increase the amount of structure in an area will involve value judgements of different components (habitats and species) because the creation of a new habitat will be at the expense of the natural one.
Ecosystem Manipulation	**POPULATION MODIFICATION**			
Ecosystem Manipulation	Restocking and stock enhancement	*Restocking* is the potential to restore target species through the release of cultured juveniles and protecting that stock until the desire population level is achieved. *Stock enhancement* supplies additional target species into the population to provide additional stock to harvest.	Restocking should be considered if all other management strategies are incapable of restoring the population to acceptable levels.	To reduce risk, restocking programs must outline hatchery procedures and quarantine protocols. Stock enhancement programs need to assess criteria such as: minimizing the production of hatchery-reared juveniles by optimizing the natural replenishment through wild stocks; estimate the abundance of predator and prey species at release sites; and assess whether the release will achieve the desired goals.
Ecosystem Manipulation	Culling	Reduce the population abundance of predators or competors of the target species to increase the yields of the desired stock.	Food web manipulation must carry out the desired effect and not result in unwanted abundance changes of target species or threaten the survival of culled species.	Consider rebuilding through other conventional management measures. Large scale culling should only occur after thorough investigation of full-scale implications of the modification have been assessed.
Ecosystem Manipulation	Intentional introductions	Fisheries can be created by the introduction of a new species.	High risk of causing unwanted changes to the ecosystem.	Comprehensive risk assessments should be undertaken to understand: the trophic level of new species, reproductive potential and requirements, species interactions, introduction of pathogens or parasites, and effects on the demand and supply of other species.

Literature Review

Biological invasions occur when an organism is introduced into a new range where the population proliferates, expands, and persists (Mack et al. 2000). These invasions can dramatically alter the balance of natural habitats through replacement of community keystone species, and by altering the environments physical features, nutrient cycles, and productivity (Betancur-R et al. 2011, Molnar et al. 2008, Mack et al. 2000). Prosperity of these established organisms differ according to environmental conditions of introduced ranges, community constraints, and mutualism (Mooney and Cleland 2001, Mack et al. 2000). Invasive species are now considered an integral component of global change being considered as detrimental as human-driven atmospheric and oceanic alterations (Molnar et al. 2008, Sakai et al. 2001, Mack et al. 2000). Many invasive species were introduced by humans, either accidentally or intentionally, as proven by the dramatic increase in organismal immigrations worldwide tracking trends in human transport and commerce (Jones 1993). Anthropogenic influenced movement of organisms is dwarfed in scope, frequency, and impact by naturally transported organisms; however, these activities have significantly increased in recent years.

Indo-Pacific lionfish (*Pterois volitans* and *P. miles*) were first sighted off the coast of Florida in the 1980s, and have become the first established non-indigenous marine fish species along the Atlantic Coast, Gulf of Mexico and Caribbean (Morris & Akins 2009). Introduced through the aquarium trade (Morris et al. 2011), their high fecundity rate, recurrent dispersal capabilities (Betancur-R et al. 2011, Schofield 2009), lack of local predators (Hackerott et al. 2013), and replacement as a mesopredator (Cote et al. 2013) have contributed to their successful expansion. Lionfish are reported to remove up to approximately 94% of small native reef fish, a rate nearly triple that of local predatory fish (Albins 2013). Because of this, they were ranked as one of the top fifteen greatest global threats to biological diversity in 2010 (Sutherland et al. 2010). Once established, a non-native marine fish is nearly impossible to eradicate (Molnar et al. 2008, Thresher & Kuris 2004, Mack et al. 2000); thus, effective strategies for managing lionfish populations are needed to retain the integrity of the ecosystem (Green et al. 2012, Cote & Maljkovic 2010). Various methods to control their numbers have been proposed on an ad-hoc basis including: lionfish culling, incidental bycatch, state and federal bounties, biologic control, and human consumption (Morris 2012). We have developed a pilot consumer-driven sustainable lionfish fishery model that balances native coral reef fish recovery with a profitable sustainable harvesting of lionfish for human consumption.

The ability of invasive marine fish species to become established is associated with a number of life-history and behavioral characteristics such as: reproductive output, larval behavior and dispersal, and post-settlement movement (Cote et al. 2013). Lionfish have remarkably high reproductive output, estimated to produce over two million eggs annually (Morris and Whitfield 2009, Morris 2009). The movement of lionfish egg masses undoubtedly contributes to their overall geographic expansion as they are believed to remain on the surface ocean spreading by wind-driven currents rather than bottom ocean currents (Betancur-R et al. 2011, Freshwater et al. 2009). Larger adult lionfish have been observed to travel considerable distances (>200m) over sand between patch reefs with occasional movements as far as 2km (Cote et al. 2013).

Population density estimates of lionfish in US coastal waters are much higher than found in their native ranges. *P. volatins* densities have been recorded at >390 lionfish per hectare (ha) in the Bahamian Archipelago (Green and Cote 2009), a value more than eighteen times greater than those reported in a previous study by Whitfield et al. 2007. Figure 4-1 shows Bahamian Coral Reefs where the biomass densities were conducted. Regions installing control mechanisms are still being heavily impacted by lionfish populations with some even experiencing exponential growth. By looking at historical and present declines in commercially and recreationally important fish species, broadly influenced by consumer demand, we can attempt to use consumer-driven fisheries to begin effectively reducing the populations of invasive species such as lionfish.

Figure 4-1. *Invasive lionfish densities on reefs in the Bahamian archipelago.* The photograph shows seven lionfish overlaying a single coral head. Some of the highest densities recorded have been found in the Bahamas. Image: Green and Cote 2009.

Lionfish cause substantial declines in abundances of native reef fishes, including adults of small species and recruits of larger commercially-sought species that would otherwise outgrow them (Cote et al. 2013). Lionfish are estimated to reduce net recruitment of prey fish by up to 94% on reef habitats. Consumption of herbivorous fish may reduce their functional role in maintaining algal populations of the reef which is critical to the health of the resident corals (Albins 2013). These invasive fish also compete for food and habitat resources with local economically important predators, such as snapper (Lutjanidae spp.) and grouper (Epinephelinae spp.) which negatively impacts commercial and recreational fishermen. Lionfish may exacerbate existing reef stressors (e.g. bleaching events, climate change, ocean acidification, overfishing, and pollution), which can accelerate degradation of ecosystem health (Morris 2012). Effects of this nature are difficult to quantify, but potentially pose one of the greatest threats to the ecosystem (Albins and Hixon 2011, Lesser and Slattery 2011).

Methods

Pilot fishery model

Integral data inputs identified for the initial model include: density and age-growth structure of lionfish; quantification of prey/predator fish biomass; income and costs assessments associated with lionfish-dedicated divers/fishermen; determination of the effectiveness of developing a consumer demand; evaluation of the sustained economic benefits for stakeholders; improvement of public awareness and involvement with lionfish removals through eco-friendly marketing strategies; and evaluation of lionfish site fidelity through acoustic tagging (Figure 4-2). It is understood and acknowledged that these inputs may be further refined and/or new inputs defined with progression of model development. For Aruba, we use our data, or identified inputs from the literature that is representative of this region for those variables not yet collected. Aruba, an island in the southern Caribbean, encompasses 180 km^2 and has a population of 112,000.

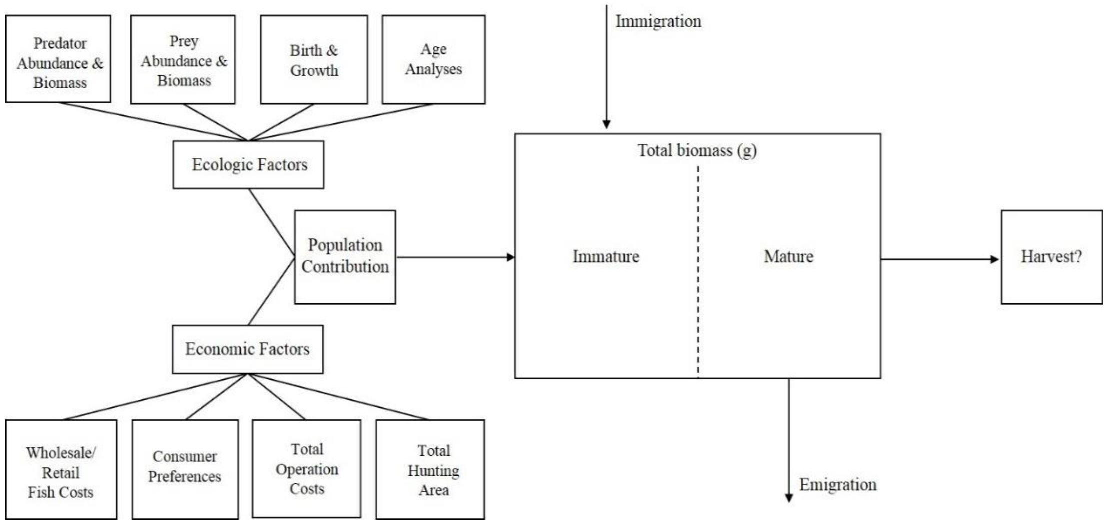


Figure 4-2. *Conceptual sustainable lionfish fishery model with anticipated input parameters and output.* It can be assumed that immigration and emigration are equal and will not require values. We use our preliminary data from Aruba to conceptually show how the output can be determined. Additional inputs will be added/modified with the continuation of this project (Walker & Jones 2015).

An important data point in many economic fisheries models is the species abundance for times prior to human intervention. Quantitative data for most fisheries extend back to perhaps the 1950s but the fisheries were negatively impacted by humans before then – resulting in shifting baseline issues (e.g. Pinnegar and Engelhard 2008). This shifting baseline issue is true for lionfish, as most areas that lionfish have invaded are currently influenced by a variety of ad-hoc human intervention methods and intensities. As such, it is difficult to determine what lionfish abundances would be in the absence of human removal efforts. Non-human intervention abundance estimates have not been obtained for Aruba, therefore, we use one of the earliest density estimates obtained near the beginning of systemic human removal intervention strategies (Green & Cote 2009). In addition, reported abundance estimates throughout their invaded range have been summarized with several estimates from marine-protected areas or areas of low human removal interventions (Table 4-2) (Elise et al. 2015). From these data points we assume an undisturbed abundance of 390 ha^{-1} for highly ideal habitat in Aruban waters.

***Table 4-2**. Lionfish densities recorded during underwater visual censuses in varied Caribbean locations as reported by Elise et al. (2015).* Values were taken directly from Elise et al. (2015) for summarization of reported lionfish densities.

Site (country or island)	**First report of lionfish**	**Date of survey**	**Mean densities (ind ha^{-1}), n=sample size**	**Reference**
Dos Mosquieses, Venezuela	Feb 2010	Mar 2013	121, n=22	Elise et al. (2015)
Los Roques area, Venezuela	Nov 2009	Mar 2013	90, n=48	Elise – unpubl data
Morrocoy area, Venezuela	Dec 2009	Jan 2013	51, n=54	Galindo – unpubl data
Bonaire, Netherlands	Nov 2009	2011	9, n=16; 31, n=16; 41, n=16; 228, n=16; 216, n=16	White (2011)
La Amistad, Costa Rica	Apr 2009	June 2011	92, n=26	Sandel (2011)
Mesoamerican Barrier Belize-Mexico	Dec 2008	May-July 2012	160	Hackerott et al. (2013)
Cozumel, Mexico	Jan 2009	2010	255	Sosa-Cordero et al. (2013)
Little Cayman Islands, UK	Feb 2008	Sep 2011	233-650	Frazer et al. (2012)
Jardines de la Reina, Cuba	Late 2007	May-June 2011	150	Hackerott et al. (2013)
New Providence, Bahamas	2004	July 2088	393, n=12	Green and Cote (2009)
Eleuthera, Bahamas	2005	2009	520	Hackerott et al. (2013)
Cape Eleuthera, Bahamas	2007	Feb 2012	300, n=60	Green et al. (2013)
North Carolina, USA	2000	2008	150, n=8	Morris and Whitfield (2009)

We estimated the total available hunting grounds of Aruba to be $100km^2$, assuming a maximum depth of 100m, to calculate the lionfish “sustainable stock”. Although divers cannot reach this depth, lionfish are found deeper than this. We assumed substrata varied in regards to optimal lionfish density distribution in Aruba, such that, 45% of available habitat are highly ideal (Habitat 1) for lionfish, 25% are ideal (Habitat 2), and 30% are non-ideal (Habitat 3) based on the approach of Bernal et al. (2015). We assumed, in the absence of human removal interventions, that 390 lionfish ha^{-1} would reside in Habitat 1, 100 lionfish ha^{-1} in Habitat 2, and 10 lionfish ha^{-1} in Habitat 3.

Green et al. (2014) concluded that removing 75-95%, depending on the habitat, of total lionfish populations allowed native prey fish populations to rebound by 50-70%, and the larger ecologically important grazers and economically important fisheries species were able to recover by 10-65%. For this model we chose to use 75% as the removal needed to allow net recruitment of prey fish to improve to a healthy status. The desired stock, following Green et al.’s (2014) removal estimates, would assume 25% retention of the total abundance.

It is estimated that female lionfish become sexually reproductive at 17.5cm tail length (TL) and males at 10cm TL (Morris 2011a). For the purpose of this model, we chose 15cm as our baseline for mature adult lionfish, as they are the ones contributing to the marketable population and from our survey data, we found that restaurant owners in Aruba would buy them at this size. Length and weight data (Figure 4-5, Results section) have been collected from Aruba (n=738) and the Flower Garden Banks National Marine Sanctuary (FGBNMS) (n=317). TL and weight (W) data are presented on the same plot to show the consistency among the two datasets. Using the samples captured from Aruba (Figure 4-5, Results section), we determined the percentage of individuals in the population that will contribute to the marketable population in the model at year one. The percent contribution of adults in Aruba is 83%, while percent contribution of juveniles is 17%.

From the lionfish collected at the FGBNMS, a subset (n=27) were dissected to calculate percent fillet yield. Fillet length, width, and weight were recorded for a subset of fish removed from the FGBNMS (Figure 4-6, Results section). A Pearson correlation was conducted for these two variables to determine if the relationship was statistically significant, the results are provided in the figure caption.

Morris et al. (2011a) examined instantaneous adult mortality rates in lionfish (0.624yr-1). We calculated instantaneous adult mortality for our sample population using the mean weight (Lorenzen 1996) from field collected specimens ranging in size 15cm – 43.5cm. The annual mortality rate is 0.648 yr^{-1}, consistent with Morris et al. (2011a); however, we exclude natural mortality from our model as human predation on lionfish will be the greatest contribution to adult mortality; therefore, we can assume natural adult mortality is zero.

Our model assumes steady state; therefore, the total biomass of fish that need to be removed each year can be determined by knowing the percentage of fish contributing to the marketable population the following year (Figure 4-5, Results section). Nearly 17% of our sample population were juveniles – we can assume they will be sexually mature the following year (Edwards et al, 2014, Morris et al. 2011a) and contribute to the marketable population.

Using local government statistics, the annual expenses for an Aruban fisherman/diver is equivalent to US$24,000, which includes living expenses, boat fuel, and mooring fees (Boekhoudt pers. comm.). In Aruba, lionfish sell for approximately US$11.00/kg ($5.00/lb). Assuming this wholesale cost, and the ideal removal needed, we estimated the current Aruban lionfish fishery value. Considering the living expenses in Aruba, we then estimated the number of dedicated lionfish fishermen/hunters the island could conceivably sustain. We further determined the catch rate necessary per diver per day to achieve the ideal removal rate each year. These results were compared to diver removal catch rates calculated from the 2014 Aruba Lionfish Derby hosted by Walker and Aruban colleagues.

Survey sample frame

It is also important to know potential consumers willingness to try a new fish resource. We conducted a series of oral-surveys with fishermen, divers, restaurant owners, government officials, locals, and tourists in Aruba during summer 2014. A survey is provided for each of the stakeholder groups interviewed (Appendix B). The sample frame for this project was identified as stakeholder groups in Aruba that are already being affected by lionfish and are likely to be impacted or influential in the establishment of a fishery. Individuals were sampled during multiple times of the day in varied locations over the course of a month to eliminate any time bias during sampling. Surveying occurred during low tourist season (tripadvisor.com), but locations tourists frequently visited were surveyed in order to generate the targeted number of responses. Resorts around the island were visited periodically during the survey month of varying economic strata as to eliminate monetary bias. There was only one rater during the survey period whom did not deviate from the script. All individuals in each group were asked the same questions in the same order. On rare occasions, if translation was needed, fellow biologist (Boekhoudt) read the questions directly from the survey to the individual participants (local fishermen). All of those surveyed provided informed consent to participate.

Each were asked a series of questions to identify their familiarity and perceptions of the invasive species, as well as their willingness to eat lionfish. Figure 4-3 shows the percentage of individuals surveyed in each category (n=117). Surveys were unique to each group of individuals, as their knowledge, experience, and contribution to creating a lionfish fishery varied.

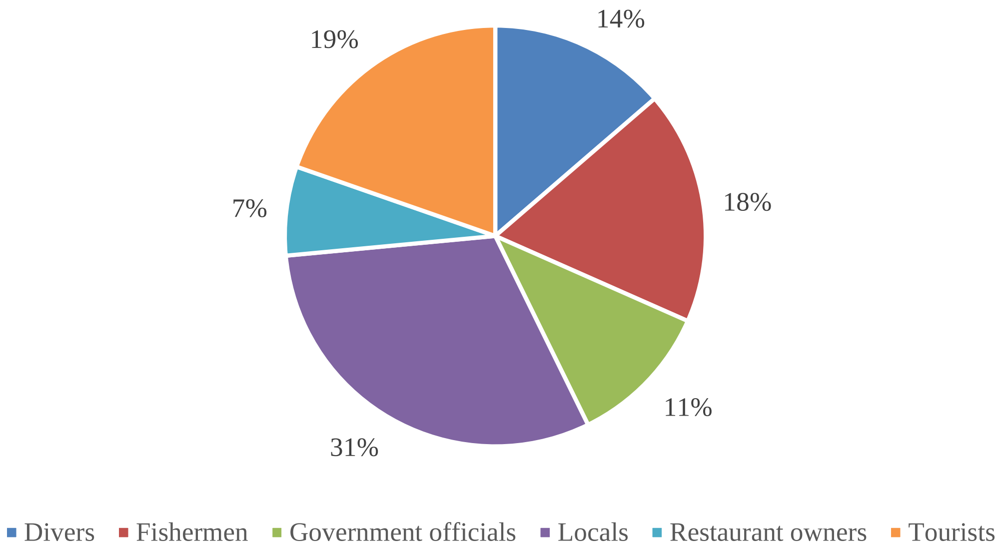


Figure 4-3. *Percentage of surveyed individuals in each of the participant categories.* The majority of those surveyed were local Arubans and tourists as they made up the largest groups.

Fishermen were questioned on their familiarity of lionfish, their willingness to participate in a lionfish fishery, and perceptions of current commercial fisheries. Divers were questioned on the frequency of lionfish encounters, participation in ad-hoc removal efforts, current consumption of lionfish and/or willingness to eat lionfish. Restaurant owners represented one of the more important groups surveyed as they will contribute greatly in fishery efforts. They were questioned on their familiarity with lionfish, experience in preparing lionfish, willingness and/or current feature of lionfish menu items, concerns with creating the fishery, and current struggles faced with attempting to serve lionfish.

Government officials were another important survey entity as they will create and mandate the regulations for a fishery, manage the health of the ecosystem and fishery, and work collaboratively with scientists to determine the most effective strategies. Officials' questions differed in that they were all open-ended, as to not bias their answers towards project goals. These individuals were questioned on their familiarity with lionfish, current concerns (if any), current regulations (if any), and perceptions on how lionfish can be used to benefit Aruba (if applicable) (Figure 4-4).

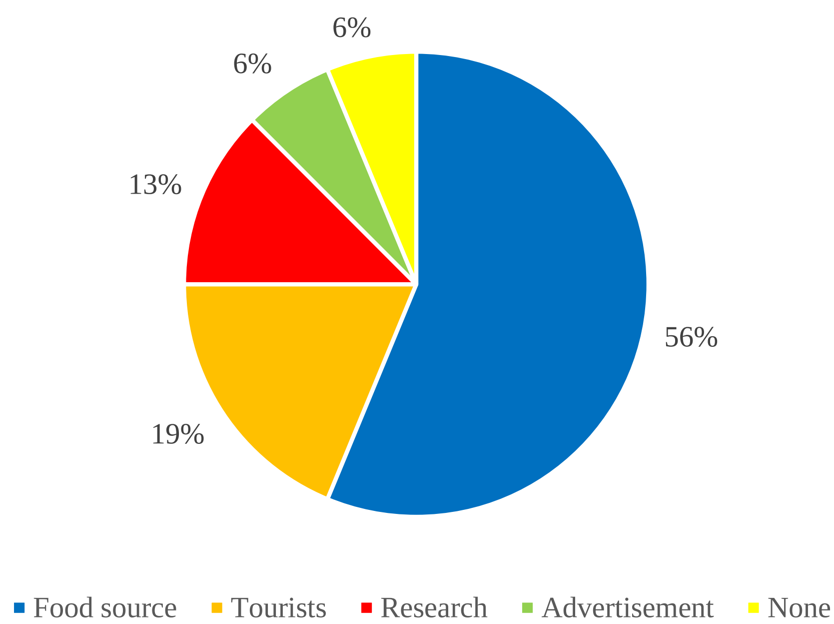


Figure 4-4. *Percentage of government official responses to benefits lionfish may bring to Aruba.* These were responses from open-ended questions regarding potential benefits of lionfish in Aruba. More than half of the government officials (n=13) interviewed considered lionfish as a food source.

Local Arubans were surveyed inland and on the coastline for variance among exposure to the marine environment. They were questioned on familiarity, current consumption (if any), and their willingness to eat lionfish. Tourists were also surveyed inland and on the coastline to achieve variability among exposure to lionfish. They were asked a series of questions on their familiarity with lionfish, number sightings while in Aruba, if they had tried lionfish, and their willingness to try them.

Results

Using the total available hunting grounds identified in Aruba with the population estimates via substrate, we calculated a total of approximately 887,000 lionfish that would occupy Aruban waters. Using the average weight of our sample, 256g, we determined that the "sustainable stock" of Aruba, assuming the necessary removal abundance, would be approximately 131,200kg. We estimated that nominally 22,300kg would need to be removed annually to keep the lionfish abundances low enough to allow juvenile reef fish to recover to healthier numbers and to maintain a sustainable lionfish fishery. Again these values will be refined as more data is collected. TL and W data were collected from Aruba and FGBNMS – both are reported on Figure 4-5.

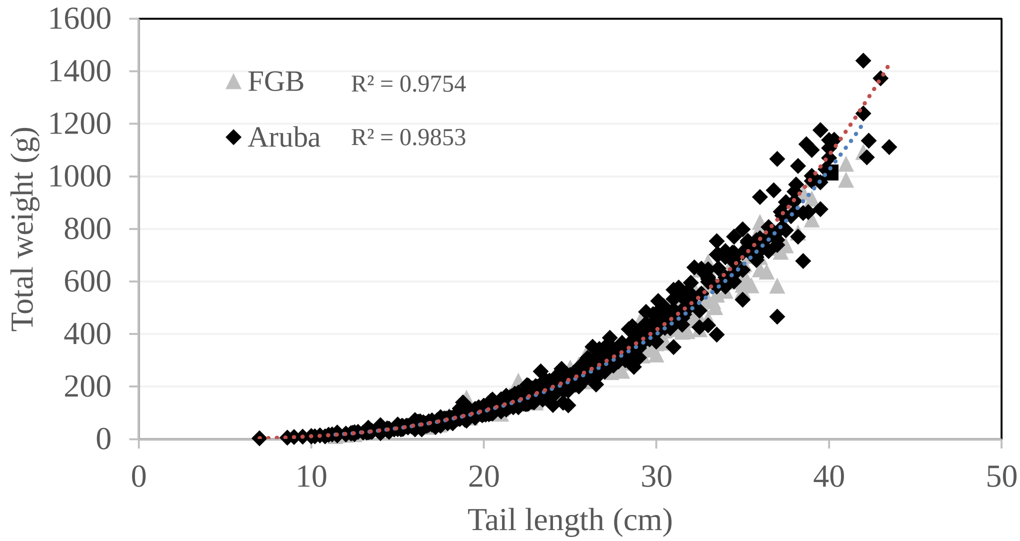


Figure 4-5. *Lionfish tail-lengths (cm) and weight (g) from Aruba (n=738) and Flower Garden Banks National Marine Sanctuary (n=317) in Galveston, TX.* Lionfish were collected from Aruba in 2014 and Galveston, TX in 2015. All fish lengths were determined with a standard fish-measuring board and weighed on the same scales to avoid equipment bias.

The mean fillet yield was 36.5% ± 0.6 standard error (SE), comparable to that reported in Morris et al (2011b). From the relationship of TL to fillet yield (Figure 4-6), we have determined the optimal size to obtain two 4oz (112 gr) fillet servings is from lionfish >32cm. Fish smaller than this may be utilized for other preparations. Aruban restaurants serving lionfish purchase fish nominally as small as 15cm, but only the larger fish are prepared for a fillet dish. The restaurants pay more per kg for the larger fish. Based on age-growth relationships determined by Edwards et al. (2014), it can be expected that fish <15cm (non-marketable) are 0-1 year olds (yo), fish 15cm-30cm (marketable size) are 1-3yo, and fish >30cm (choice size) are 4+yo.

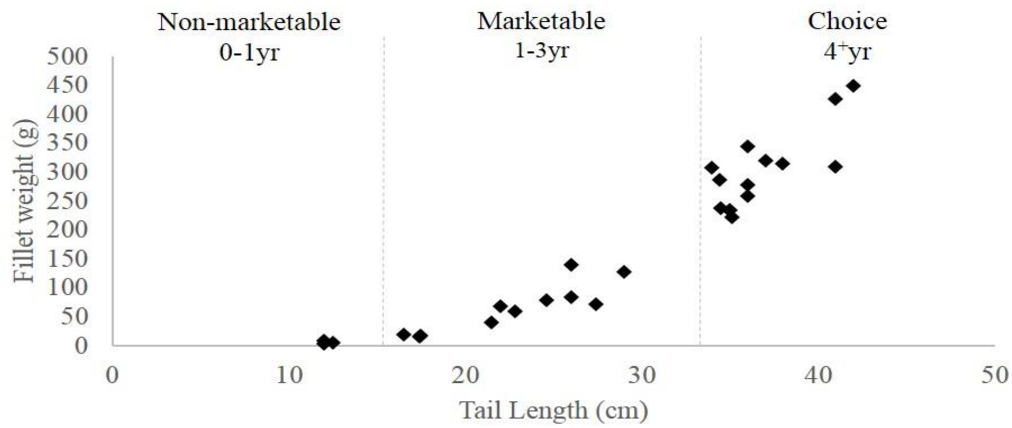


Figure 4-6. *The total fillet weight (2 fillets per fish) vs. tail length (cm).* All fillet data was collected from lionfish removed from Galveston/FGB. The vertical dashed lines indicate the minimum recommended size for fish that are going to be used in restaurants and the minimum size for fish used as a fillet serving, assuming a 4oz (~112g) fillet (p-value <0.01).

Assuming the reported wholesale cost (US$11.00/kg), and the ideal removal needed (22,300kg), we valued the Aruban lionfish fishery at US$246,000. Considering the total living expenses in Aruba (US$24,000), the fishery could support ten dedicated lionfish fishermen/hunters. Assuming these values, each fisherman would need to remove nearly 180kg of lionfish per month. This number can be reduced, if consumer demand increases, and lionfish afford a higher dollar value per kilogram sold ($/kg). Assuming each fisherman works 20 days/month and each day comprises four one-hour dives, the hourly harvest rate would have to average 2.5kg. Dives during the 2014 Aruba Lionfish Derby, hosted by graduate student Walker and Aruban colleagues, averaged 2kg per person per one-hour dive. All of the model input values calculated have been summarized in Table 4-3 for ease of reference.

Table 4-3. *Summary of model input values as calculated with our preliminary data or as found relevant in the current literature.* It is acknowledged that these estimates may be high and/or low, and therefore will be refined as more data is collected for this region.

Variable	***Calculated Value***	***Source***
Lionfish abundance	887,000 lionfish	This study; Bernal et al. 2015; Green and Cote 2009
Available hunting grounds	100km^2	This study
Sustainable stock	131,200kg	This study
Annual removal	22,300kg	This study
Annual mortality	0.648yr^{-1} (negligible)	This study
Marketable fish sizes	Non-marketable (<17cm); Marketable (15-30cm); Choice (>30cm)	This study
Annual expenses	US$24,000	Boekhoudt, pers comm
Value of fishery	US$246,000	This study
Harvest rate	2.5kg hr^{-1} diver^{-1}	This study
Total supported divers	10	This study

During the surveys, individuals classified in the groups of divers, locals, and tourists were asked if they had eaten lionfish before, and whether they were willing to eat it if they had not already tried it (Figure 4-7). Only two divers had not tried lionfish, one of which was willing to try, while the other was not willing to try it. This diver did not specify why they would not consumer lionfish. Of locals surveyed, one identified they do not eat fish, but would try lionfish if it were deemed eco-friendly. Two locals said they eat fish, but would not try lionfish and did not specify why. Another local that does not eat fish would not eat lionfish. Two tourists that do not eat seafood were willing to try lionfish. Five tourists that eat seafood were not willing to try lionfish but did not specify why. One tourist only eats shellfish, and therefore, would not try lionfish.

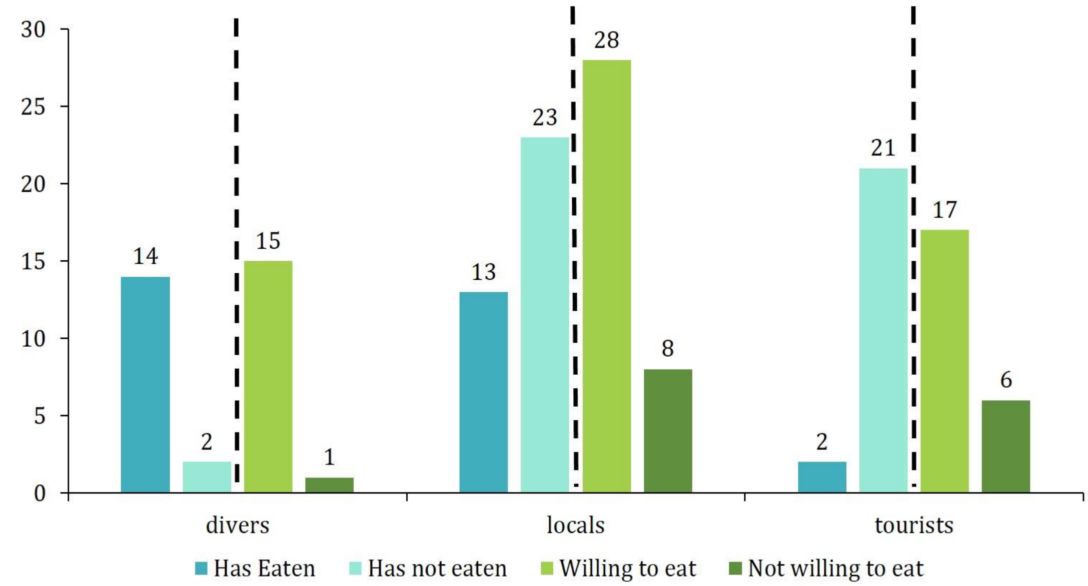


Figure 4-7. *Survey results of patrons who have tried lionfish or are willing to try it.* These are results of 75 patrons surveyed in the groups of divers, locals, and tourists on two different questions: whether they had already eaten lionfish (Yes or No); and whether they were willing to eat lionfish or not (Yes or No). We have included the dashed line to separate the results of the two questions to show the results. The numbers above the blue columns will add to be the same number as those shown over the green columns. For example, people that have already eaten lionfish will be included in the "willing to eat" column.

Of the 117 individuals surveyed, only 75 were asked if they had consumed lionfish or if they were willing to consume it. Eighty percent were willing to try lionfish, of which only three individuals that did not eat seafood were willing to try the fish if deemed eco-friendly. Approximately 61% of those surveyed had not already tried lionfish, the majority of which were locals and tourists (50% locals, ~46% tourists).

We have designed the first pilot-fisheries model to create a sustainable lionfish fishery, using the approach of consumer-driven demand. There is currently no technology to mass capture or produce lionfish, therefore, we are making lionfish a luxury consumer item rather than a commodity due to the lack of technology. As shown in the previous chapters, we can conceivably argue that with effective management and marketing strategies, consumer-driven demand control targeted fisheries, and therefore, if created, can be used to establish a lionfish fishery. This will provide consistent need for lionfish removal, while also offering economic incentives to those fisherman dedicated to lionfish harvesting.

Discussion

Thus far, the largest initiative for combating lionfish involves ad-hoc removals by recreational divers in derby events (Morris & Whitfield 2009, Barbour et al. 2011). Development of a commercial or recreational fishery has been proposed as a long-term management strategy, but has yet to be well quantified or defined. Here we have been the first to quantitatively analyze the establishment of a lionfish fishery in Aruba with preliminary data through the development of a pilot consumer-driven model.

Conceivably, fisherman could reduce the number of lionfish needed to be caught to sustain economic sustainability if consumer demand increases and lionfish afford a higher dollar value per kilogram sold. Although an increase $/kg may reduce the number of fish needed to be caught in order for fishermen to sustain a livelihood, they must still remove 17% of the population annually to retain a "healthy" ecosystem. If the $/kg were increased by changes in Aruban consumer demand for lionfish, this would afford an increase in the number of divers that can be supported or an increase in income per diver. If harvesting were restricted to local stakeholders responsible for the lionfish hunting grounds, a common property-based management policy could be effectively employed (Ko et al. 2010).

Utilizing human consumption to reduce invasive species populations distinguishes a removal effort that constitutes both environmental and socio-economic benefits (e.g. Varble & Secchi 2013, Nunez et al. 2012). Our model is designed to quantify the annual lionfish harvest needed to remove nominally 75% of the lionfish population to achieve healthy reef fish recovery (Green et al. 2014), and to determine the sustainable economic impact of such harvesting. As such, the model is both ecologic (i.e. allowing native reef fish populations to rebound which will benefit the overall health of the reef) and economic (i.e. the value of creating a "sustainable" lionfish fishery with its attendant employment and economic benefits). Difficulties arise with quantifying the economic impacts of lionfish, whereas ecological impacts are much easier to quantify because it is directly reflected in the resident fish populations. Prevention and control of the lionfish invasion will require a long-term, ecosystem-based strategy rather than focused tactical approach (Mack et al. 2000).

Eradication of lionfish is not likely, however, suppressing the population to a manageable level is obtainable. Controlling invasive species varies immensely in effort, therefore, employing a long-term, ecosystem-based management strategy is the most effective approach. Success of such approaches will depend more on commitment and continuation than efficiency of the specific strategy. Failing to address issues of biotic invasions can result in severe global consequences, including wholesale loss of fishery resources; disruption of the ecological processes that supply natural services to human enterprise; and creation of homogenous, impoverished ecosystems composed of cosmopolitan species (Mack et al. 2000).

Greater public and governmental awareness of chronic and global effects of lionfish (Morris 2009) must be addressed as many remain unaware of the severity of the issue. Arousal of public and government concern for invasive species has proved difficult; gaining support for prevention and control often fails because of a lack of understanding of the inevitable link between nature and the economy. The threats posed to biodiversity and ecosystem-level processes directly translates into economic consequences through the loss of fisheries and consequent imbalance in ecosystem structure (Mack et al. 2000). Invasive species cause economic losses through fishery reductions, directs costs with combating the issue, and indirectly with potential human health concerns (Mack et al. 2000). The ensuing potential economic consequences of lionfish has yet to be estimated; though, it is clear that their invasion directly competes with native, commercially valuable species and, in turn, affects the economic viability of such fisheries. It is to the benefit of communities to consider using lionfish for economic gain rather than cost through a sustained consumer-driven fishery.

Conclusion

Lionfish have successfully invaded the Atlantic Coast, Gulf of Mexico and Caribbean, and there is no possibility of eradicating them. To-date, a number of management strategies have been explored on an ad-hoc basis to reduce/control their numbers throughout their invaded range. However, without a systems approach (i.e ecologic and economic) to the problem even successful ad-hoc management strategies cannot be effectively evaluated. Our work was designed to provide a tool to quantitatively evaluate a management strategy that involves the creation of a “sustainable” lionfish fishery.

Additional Research Needed

The lionfish research outlined in Chapter IV will be continued and refined for the PhD dissertation. Additional model inputs may be refined or new ones defined as the project expands. Data that has not been collected in Aruba (i.e. abundance estimates and substrata dispersion) will be collected during field studies for the PhD. These values will then be added to refine the current pilot-fisheries model. Age-based data will also be obtained for Aruba via otolith-analysis to determine the consistency of age-estimates and evaluate if these are generally applicable.

As this model is generally applicable, we plan to expand this project to other regions such as: the Gulf of Mexico, Florida Keys, and Puerto Rico. This will afford variability in outputs as each of these locations offers differences in removal efforts, lionfish density severity, socio-economic factors, and management strategies. Parameter estimates for the model may change pending further analyses after the additional data collection.

CHAPTER V

CONCLUSION

Fisheries have been depleted for a long time, and many of them unsustainable for much longer than originally perceived. The earliest sophisticated fishing tools discovered to date were recovered from a 90,000-year-old archaeology site in Africa. The main target species was identified as a freshwater catfish that is now-extinct, so it is likely the fisher's transitioned to a new fishery (Pauly et al. 2005). The notion of exterminating a fishery population, then moving onto a new species, has occurred ever since with short periods of 'sustainability' as a result of limited-range exploitation, unsecured subsidies, or technical limitations (Pauly et al. 2005). Extracting scientific data from historical databases can aid in changing the perception that fishing practices do not heavily impact fish populations as it shows the status of previously pristine ecosystems, as well as, defining species that were driven to commercial or even species extinction prior to the establishment of the National Marine Fisheries Services (NMFS) commercial dataset.

NMFS began compiling commercial landings data in 1950 with their respective wholesale value; however, it is understood that many species were heavily exploited prior to this. Scientists and managers recognize the importance of reconstructing this type of data to earlier times to understand the interaction between humans and their impacts on marine species prior to the government datasets (e.g. Pitcher 2001, MacKenzie et al. 2002, Rosenberg et al. 2005, O'Connor et al. 2011, Ferretti et al. 2013, McCauley et al. 2015).

Such heavy anthropogenic modification has increased the necessity for understanding historical conditions, in order to provide a more robust baseline to assess future changes (e.g. Lotze and Worm, 2008; Ermgassen et al., 2012). The majority of fisheries statistics data and management practices are determined using standing stock abundance analyses; although this data is necessary, it does not consider the effects of consumer demand in shifting ecosystem baselines – this defines the purpose of this thesis.

Very few studies have utilized archival data to assess fisheries from a trophic-response level: Levin and Dufault (2010) with cookbooks, Van Houtan et al. (2013) with menus, and Thurstan et al. (2014) with government reports and surveys. Only one study, Jones (2008) with seafood menus, has incorporated prices to track the inflation rate of a dish as it grew in popularity. To date, there have been no studies that used historical price data to study ecosystem-level effects of consumer-driven demand. In this thesis we completed both a single-species price assessment (i.e. Diamondback terrapin – Chapter II) and a multi-species-ecosystem-level price analyses (i.e. United West Coast Fisheries – Chapter III), using historical restaurant menus and contemporary regional newspapers. With this, we then explored the idea of using the information gathered from these historically consumer-driven demanded species, to conceptualize the establishment of a consumer-driven fishery as a means to control an invasive marine species – Indo-Pacific lionfish (Chapter IV).

Chapter two showed the exploitation of a previously disturbed marine resource of Chesapeake Bay, Diamondback terrapin (*Malaclemys terrapin*), which reached commercial extinction in the early 1920's. This was completed through interpretation of prices extracted from historical newspapers and menus to create the most comprehensive and only database for this region. Given the quantity of historical menus and newspaper articles, only those with relevant information were retained. This was the first attempt to reconstruct the depletion of this marine species, therefore, the manuscript is being submitted to *Marine Ecology Progress Series*, a journal widely referenced by historical marine ecologists.

In Chapter III we presented using seafood menus from the US West Coast as a means to hindcast NMFS commercial datasets to determine the trends in inflation adjusted prices of seafood items frequently featured, as well as, an analyses of these seafood items according to trophic level placements. This was the first study to interpret this type of analysis for an entire ecosystem, as well as, the first to complete a trophic-level assessment with retail prices. Our study answers a valuable question about local seafood consumption patterns and gives insight into potential changes in consumer preferences, which can be used if applied appropriately, in fisheries based management practices (Manez et al. 2014). It was an exploration of conceptual and methodological approaches for showing consumer-preference ('Eating down marine food webs') vs. fishing effort ('Fishing down marine food webs'). A manuscript is anticipated to be submitted in a peer-reviewed journal.

The consumption, frequency, and preference of seafood items are affected by social, cultural, and geographic characteristics of consumers (Can et al. 2015, Pieniak et al. 2011). This change in consumer preference leads to changes in the species, community, and ecosystem structure of the marine realm. As many top predators have been over exploited, smaller, more vulnerable species have been targeted to sustain demand (Pauly and Watson 2003). These studies of tracking retail price fluctuations have demonstrated the 'shifting baseline' scenario of fisheries by revealing previous exploitations of fishes unidentified by currently available data. It is crucial to contextualize historical perceptions of marine resources to better implement future management strategies (Bolster 2006). This lead to Chapter III whereby we used concepts learned from historical data to determine the likelihood of establishing a consumer-driven fishery for the invasive Indo-Pacific lionfish in Aruba.

Chapter four conceptualized using consumer driven-demand to create a new fishery to combat the invasive lionfish (*Pterois volitans and miles*) in Aruba. Once a marine invasive has become established, there is no way to eradicate them (Mack et al. 2000), therefore, the population must be suppressed to a manageable level. Lionfish were designated as one of the top 15 global threats to marine biodiversity in 2011 (Sutherland et al. 2010), exacerbating the need for control mechanisms. This chapter demonstrated a preliminary conceptual model used to determine that Aruba could conceivably support ten dedicated lionfish fishermen. This study will continue to be refined and expand into my PhD dissertation at Texas A&M University at Galveston.

This thesis encompassed multiple disciplines including: biology, economics, history, ecology, sociology, and fisheries management. Being the first of its kind, the objective was to develop new methods to analyze these largely untapped archival data resources, as well as, analyze the price trends of the economically important marine species. Qualitative and quantitative data was compiled of the various commercial species to determine the exploitation of fish along the coastal United States and to reconstruct 150 years of consumer-driven demand and supply depletion. Finally, the use of consumer demand to re-mediate the invasion of a non-indigenous species was reviewed for the island of Aruba. Overall this study encompassed past (19^{th} century), present (20^{th} century), and future (21^{st} century) impacts of consumer-driven demand on marine species and ecosystems. Each of the studies presented are stand-alone with an inter-connected theme of utilizing consumer preferences as a complimentary tool for current management strategies.

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APPENDIX A

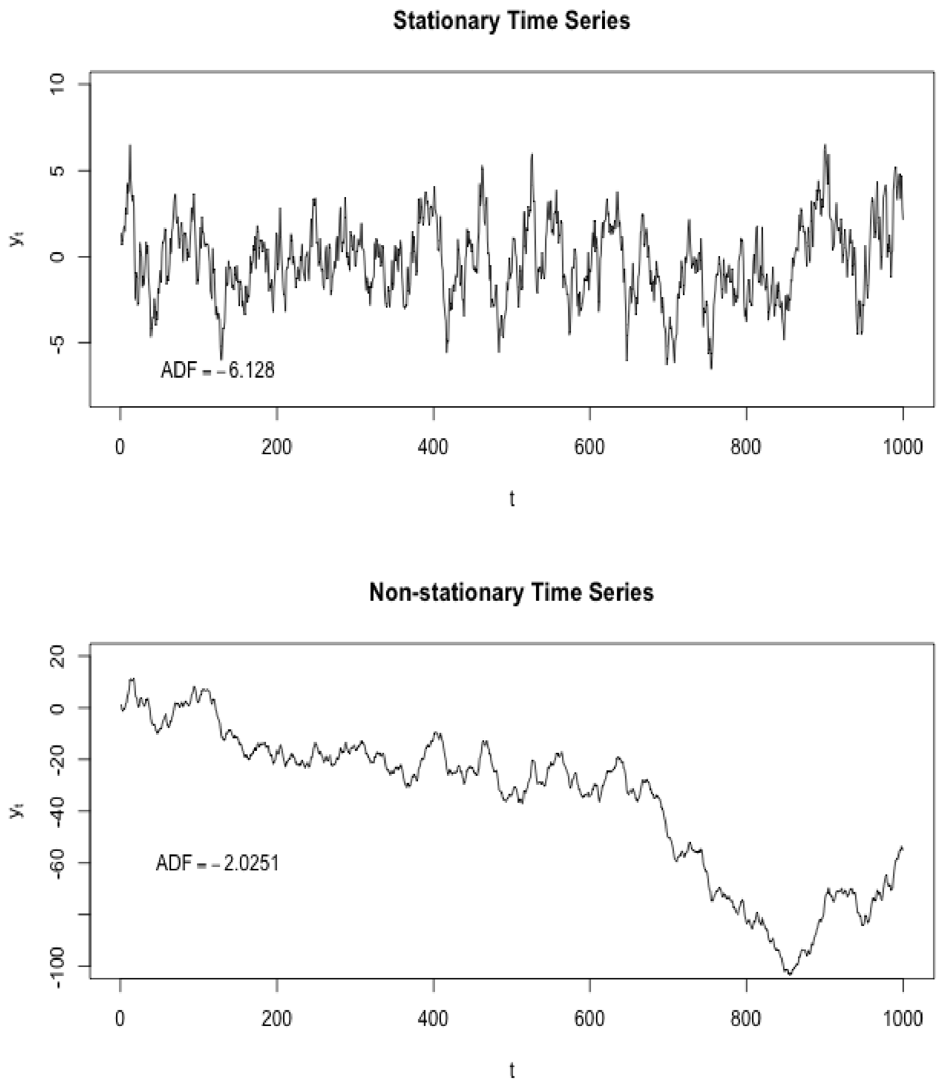

Figure A-1. *Examples of a stationary and non-stationary time series*. If a series is stationary, the data does not show a trend, rather fluctuates about some reference point, such as zero. It the series is non-stationary, it forms a trend. Images retrieved from www.wikipedia.org on 15 March 2016.

Table A-1. *List of common species names in their respective species category and the number of entries extracted from contemporary menus.* The list shows the total number of species and their respective number of entries found on all the menus. It also provides the total number of entries overall.

Common Name	***Species Category***	***Number of Entries***
Chicken	Avian	98
Flounder	Demersal	10
Halibut	Demersal	242
Rex Sole	Demersal	217
Sand Dab	Demersal	201
Sculpin	Demersal	5
Sole	Demersal	152
Sturgeon	Demersal	14
Turbot	Demersal	50
Haddock	Demersal	107
Cod	Demersal	183
Canvasback Duck	Game bird	7
Crab	Invertebrate	830
Lobster	Invertebrate	471
Prawn	Invertebrate	375
Shrimp	Invertebrate	368
Abalone	Invertebrate-Mollusc	244
Clam	Invertebrate-Mollusc	734
Mussel	Invertebrate-Mollusc	19
Oyster	Invertebrate-Mollusc	1180
Scallops	Invertebrate-Mollusc	269
Squid	Invertebrate-mollusc	56
Yellowtail (amberjack)	Pelagic - large	13
Barracuda	Pelagic-large	73
Mahi Mahi	Pelagic-large	20
Shark	Pelagic-large	7
Swordfish	Pelagic-large	174
Totoaba	Pelagic-large	2
Tuna	Pelagic-large	16
Wahoo	Pelagic-large	1
Black Bass	Pelagic-medium	2
Blue Fish	Pelagic-medium	1
Corvina	Pelagic-medium	4
Red Snapper	Pelagic-medium	48
Rock Bass	Pelagic-medium	15
Salmon	Pelagic-medium	286
Striped bass	Pelagic-medium	27
Sea Bass	Pelagic-medium	181
Anchoives	Pelagic-small	16
Herring	Pelagic-small	22
Mackerel	Pelagic-small	61
Pompano	Pelagic-small	24
Sardines	Pelagic-small	17
Shad	Pelagic-small	8
Skate	Ray	4
Diamondback terrapin	Reptile	22
Turtle	Reptile	121
Total Number of entries		**6997**

Table A-2. *List of species that were excluded from further analyses due to the insufficient number of prices.* We determined the number of entries needed for sufficient data usage to be 60 entries. This list includes species that had fewer entries than 60 and were therefore omitted from further analyses and comparison with NMFS data.

Common Name	***Species Category***	***Number of Entries***
Wahoo	Pelagic-large	1
Blue Fish	Pelagic-medium	1
Totoaba	Pelagic-large	2
Black Bass	Pelagic-medium	2
Corvina	Pelagic-medium	4
Skate	Ray	4
Sculpin	Demersal	5
Canvasback Duck	Game bird	7
Shark	Pelagic-large	7
Shad	Pelagic-small	8
Flounder	Demersal	10
Yellowtail (amberjack)	Pelagic - large	13
Sturgeon	Demersal	14
Rock Bass	Pelagic-medium	15
Tuna	Pelagic-large	16
Anchoives	Pelagic-small	16
Sardines	Pelagic-small	17
Mussel	Invertebrate-Mollusc	19
Mahi Mahi	Pelagic-large	20
Herring	Pelagic-small	22
Diamondback terrapin	Reptile	22
Pompano	Pelagic-small	24
Striped bass	Pelagic-medium	27
Red Snapper	Pelagic-medium	48
Turbot	Demersal	50
Squid	Invertebrate-mollusc	56

Table A-3. *List of species not included for further analyses distinguished by different colors according to the reason for their respective omission (Green, Blue, Orange, and Purple).* The two species highlighted in green were omitted because their origin is difficult to place. The three species highlighted in blue are species popular on the Atlantic, rather than Pacific coast and would not be representative of the Pacific ecosystem. The three species highlighted in orange are all flat-fish species that were found on the Pacific Coast, but the names were often interchanged for similar flat-fish. We chose to use the two most favored/common (i.e. Rex Sole and Sand dabs). Halibut were a much larger fish species and the subsequent prices are likely ill-representative of the demersal fish populations. The two species highlighted in purple are not regularly, nor solely, found on the Pacific Coast.

Common Name	***Species Category***	***Number of Entries***
Chicken	Avian	98
Turtle	Reptile	121
Cod	Demersal	183
Scallops	Invertebrate-Mollusc	269
Lobster	Invertebrate	471
Sole	Demersal	152
Haddock	Demersal	107
Halibut	Demersal	242
Shrimp	Invertebrate	368
Prawn	Invertebrate	375

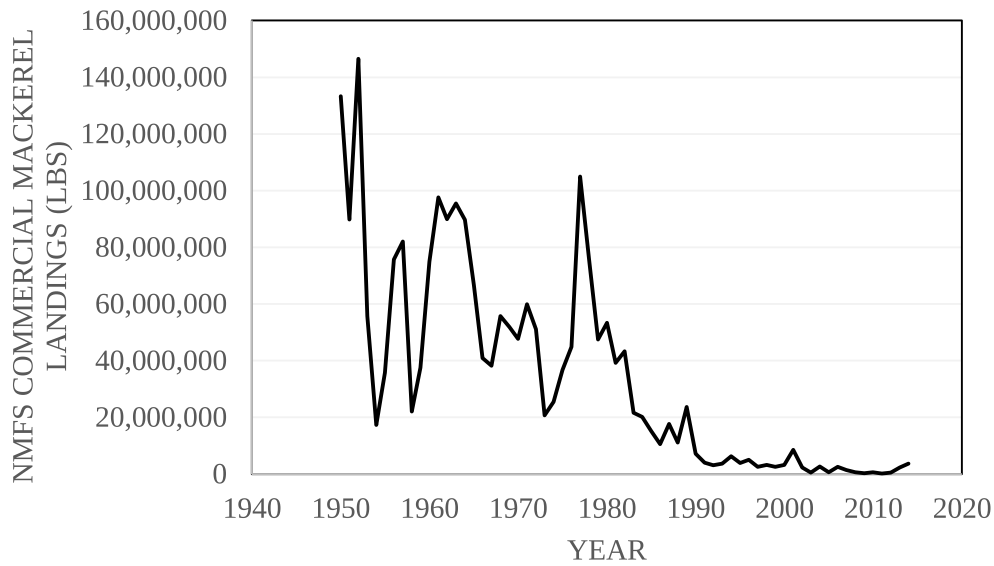

Figure A-2*. The commercial harvest of Jack Mackerel as reported by the National Marine Fisheries Services*. The supply continues to decrease, as well as, the wholesale $/lb broadly indicating a lack in consumer demand.

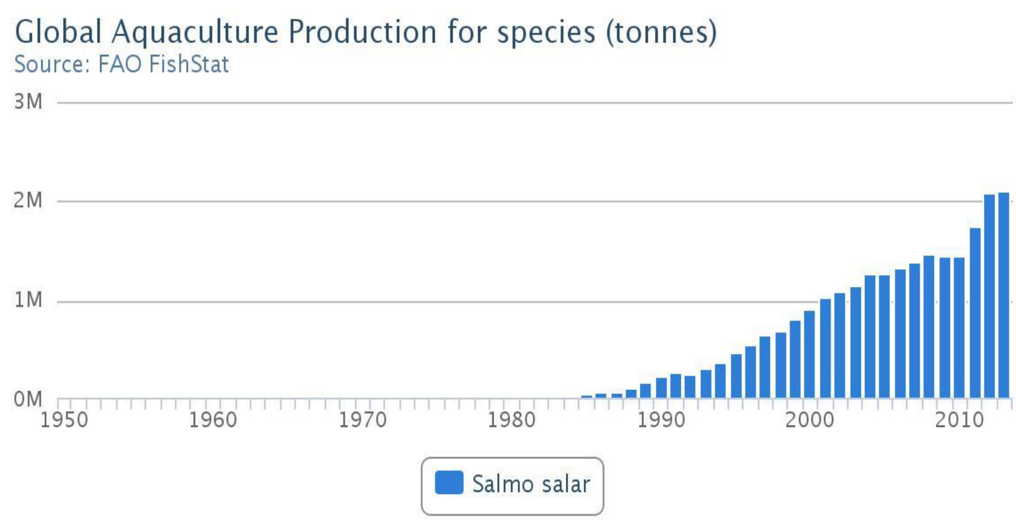

Figure A-3. *Global aquaculture production for Salmon species (FAO 2014)*. Figure can be retrieved from http://www.fao.org/fishery/species/2929/en.

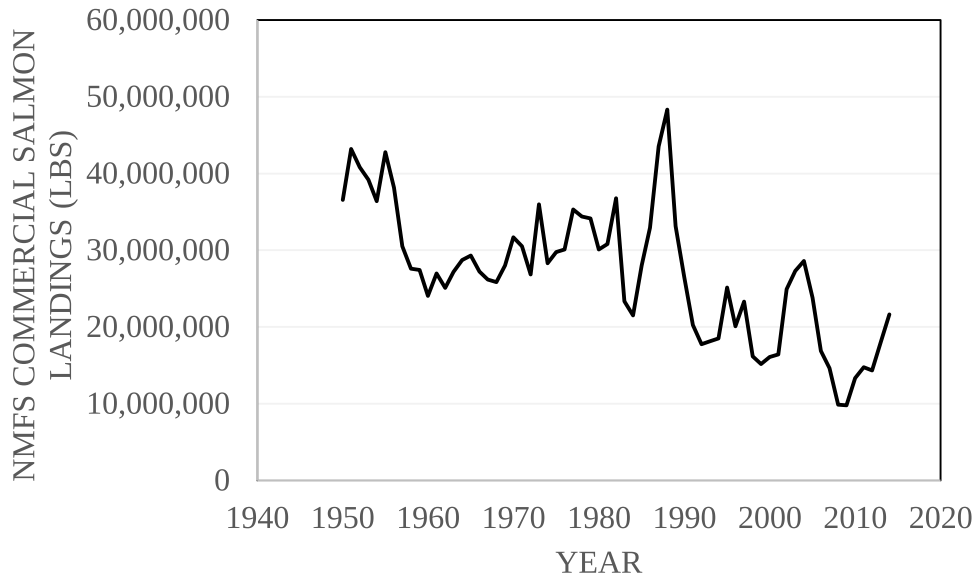

Figure A-4. *The commercial landings of Chinook salmon as reported by the National Marine Fisheries Services*. The supply peaks just before 1990, and then continues to decrease through the 1990s-2000s. This decrease occurs at the time the aquaculture production increases, suggesting aquaculture began supplying salmon to the retail fish markets. We see a consistent retail \$/dish for salmon, therefore, further suggesting the restaurants were being supplied with aquaculture salmon, rather than wild-caught.

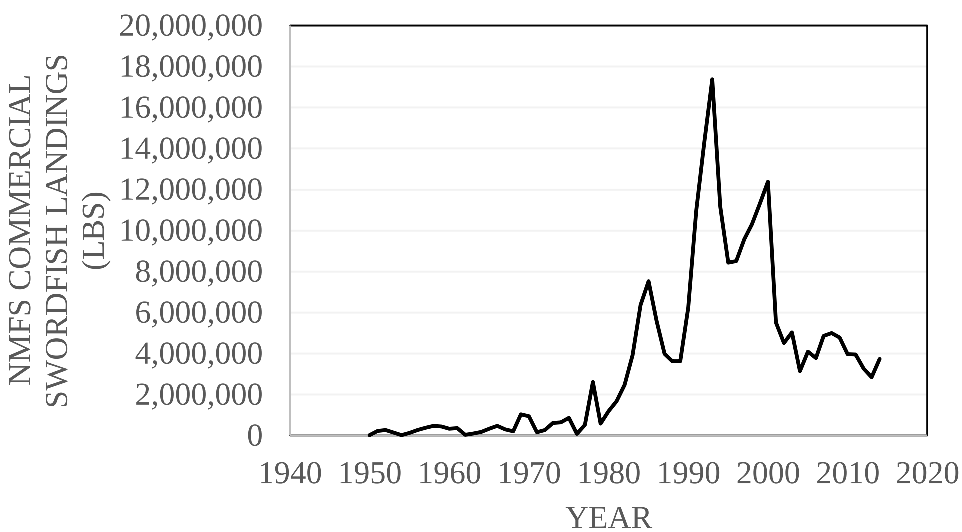

Figure A-5*. The commercial landings for Swordfish as reported by the National Marine Fisheries Services.* The greatest commercial landings for Swordfish occurred in the 1990's which coincides with a decline in wholesale \$/lb. The catch is significantly lower after the 2000's which is also represented by low wholesale \$/lb. The retail menu prices remain consistent, broadly suggesting there is a lack of consumer-demand. With decreasing wholesale prices and commercial landings, but continued retail prices, we can assume the consumer-driven demand is decreasing likely due to patrons health concerns.

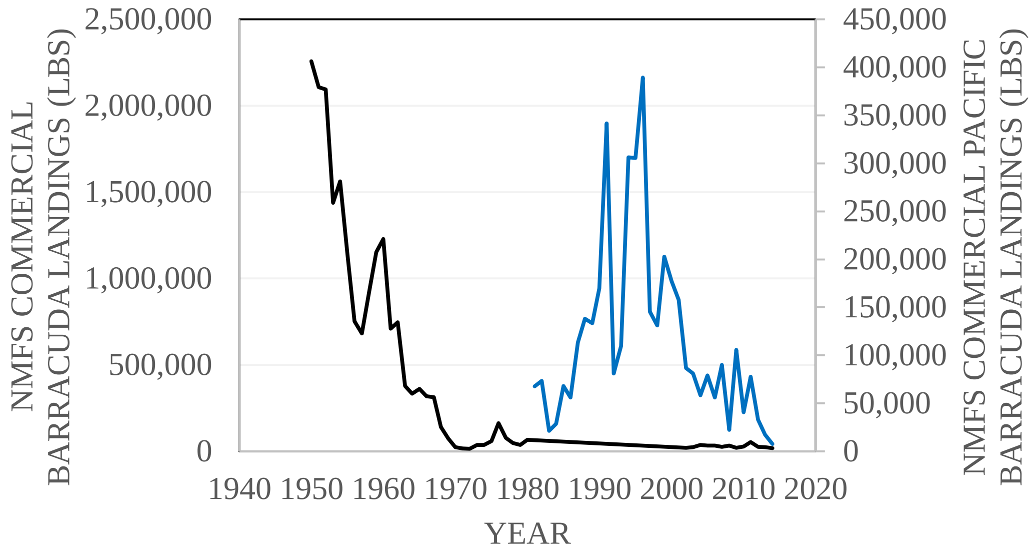

Figure A-6. *The commercial landings for Barracuda and Pacific Barracuda as reported by the National Marine Fisheries Services.* Commercial landings for Barracuda caught on the Pacific Coast and landings for Pacific Barracuda are reported here, as it appears that as the commercial landings for Barracuda nearly disappeared, the landings for Pacific Barracuda began. In the late 1990s when commercial landings for Pacific Barracuda were the greatest, the wholesale $/lb began declining. The wholesale $/lb and commercial landings continue to decrease into the 21st century, likely due to a lack in consumer demand because of growing health concerns among patrons.

APPENDIX B

SURVEY FOR FISHERMEN

Age Category (*circle one*): 20-40 40-60 >60 Male/Female (*circle one*)

1. How long have you lived in Aruba? (*circle one*)
   a. <5 years
   b. 5-10 years
   c. 10-15 years
   d. >15 years

2. What brought you here if moving from another location (*circle one*)
   a. Family
   b. Job opportunity
   c. Retirement
   d. Other(specify):____

3. How long have you been fishing? (*circle one*)
   a. <5 years
   b. 5-10 years
   c. 10-15 years
   d. >15 years

4. How many times a week do you fish? (*circle one*)
   a. 1-3 times
   b. 3-5 times
   c. 5-7 times
   d. >7 times

5. How many pounds/kg of fish do you normally catch in a week? (*circle one*)
   a. <25lbs (<11.5kgs)
   b. 25-50lbs (11.5-22.25kgs)
   c. 50-75lbs (22.25-33.5kgs)
   d. 75-100lbs (33.5-44.5kgs)
   e. >100lbs (>44.5kgs)

6. What fish do you normally catch? (*List some common ones*)____________
   ____
   ____

7. Do you fish for yourself, a hobby, or is it your livelihood? (*check most appropriate*)
   - ☐ Self
   - ☐ Hobby
   - ☐ Livelihood

   a. What do you do with the fish? (*check all that apply*)
   - ☐ Sell **_If check, include question 7b_**
   - ☐ Keep
   - ☐ Release
   - ☐ Other(specify)____

   b. Where do you sell the fish? (*check all that apply*)
   - ☐ Local market
   - ☐ Local restaurant
   - ☐ Export out of the country
   - ☐ Personal home
   - ☐ Family members home
   - ☐ Other(specify):____

   c. What methods of fishing do you commonly use? (*check all that apply*)
   - ☐ Hook and line
   - ☐ Net
   - ☐ Polespear
   - ☐ Slingshot spear gun
   - ☐ Other(specify):____

**I will show an image of a lionfish to those being surveyed to ask the next series of questions.*

8. Have you seen this fish before? **Y** or **N** (*circle one*) **_If NO, go to question 11_**

   a. Do you know the name of it? **Y** or **N** (*circle one*)

   b. What is it?____

   c. Where did you see them (*check all that apply*)
   - ☐ News (online or televised)
   - ☐ Scientific journal
   - ☐ Personal research/interest
   - ☐ Diving/snorkeling/swimming **_If checked, see d and e_**

- ☐ Fishing
- ☐ Documentary
- ☐ Menu/seafood market
- ☐ Other(specify)____

d. How many times did you see it in the ocean? (*check one*)
- ☐ <5
- ☐ 5-10
- ☐ 10-15
- ☐ >15

e. How many did you see? (*check one*)
- ☐ <5
- ☐ 5-10
- ☐ 10-15
- ☐ >15

9. Have you caught this fish before? **Y** or **N** (*circle one*) ***If NO, go to question 10***

a. How many do you normally catch each time you fish? (*check one*)
- ☐ <5
- ☐ 5-10
- ☐ 10-15
- ☐ >15

b. What do you do with the fish after being caught? (*check all that apply*)
- ☐ Released
- ☐ Discarded
- ☐ Used for bait
- ☐ Sold to restaurants
- ☐ Personally consumed
- ☐ Other(specify):____

10. Have you been impacted by lionfish? **Y** or **N** (*circle one*) ***If NO, go to question 11***

a. How have you been impacted by lionfish? (*check all that apply*)
- ☐ Loss of income
- ☐ Loss in capture of target fish

- ☐ Loss of equipment
- ☐ Bad reputation
- ☐ Change in fishing techniques
- ☐ Increased income
- ☐ Improvements in fishing techniques
- ☐ Increase capture of fish
- ☐ None
- ☐ Other(specify):____

11. Is there seasonality to the fish you catch? **Y** or **N** (*circle one*) ***If NO, go to question 12***
    a. Has this changed in the last 10 years? **Y** or **N** (*circle one*)
    b. **If so**, why do you think that is?____________________________________
    ____
    ____

12. Would you participate in organized lionfish tournaments, competitions or hunts? **Y** or **N** (*circle one*)

13. Would you be willing to catch and sell lionfish if it were eco-friendly and/or if it benefited Aruba's economy? **Y** or **N** (*circle one*)

Figure B-1. *Example of the survey read to fishermen in Aruba.*

SURVEY FOR DIVERS

Age Category (*circle one*): 20-40 40-60 >60 Male/Female (*circle one*)

1. How long have you lived in Aruba? (*circle one*)
    a. <5 years
    b. 5-10 years
    c. 10-15 years

d. >15 years

2. What brought you here if moving from another location (*circle one*)
   a. Family
   b. Job opportunity
   c. Retirement
   d. Other(specify):____

3. How many times do you dive in a week? (*check one*)
   a. <5
   b. 5-10
   c. 10-15
   d. >15

4. Do you offer dives to tourists, locals, or both? (*check most appropriate*)
   i. Tourists
   ii. Locals
   iii. Both

5. Do you educate clients on the natural environment such as identifying important fish, locations, plants, conservation efforts, etc. **Y** or **N** (*circle one*)

** I will show an image of a lionfish to those being surveyed to ask the next series of questions.*

6. Have you ever seen this fish before? **Y** or **N** (*circle one*) ***If NO, go to question 7***
   a. Do you know what the name is? **Y** or **N** (*circle one*)
   b. What is it?_______________________________
   c. Where did you see them? (*check all that apply*)
      i. News (online or televised)
      ii. Scientific journal
      iii. Personal research/interest

iv. Diving/snorkeling/swimming ***If checked, go to d and e***

v. Fishing

vi. Documentary

vii. Menu/seafood market

viii. Other(specify)____

d. How many times do you see them each dive? (*check most appropriate*)

i. <5

ii. 5-10

iii. 10-15

iv. >15

e. How many do you see at a time diving? (*check most appropriate*)

i. <5

ii. 5-10

iii. 10-15

iv. >15

7. Have you experienced any of the following with regards to a lionfish? ***If NO, go to question 8***

i. Loss of money

ii. Change in dive locations

iii. Decrease in activities offered

iv. Increased revenue

v. New dive locations

vi. Increase in activities offered

vii. None of the above

8. Do you participate in organized lionfish tournaments, competitions, hunts? **Y** or **N** (*circle one*)

If NO, go to question 9

a. How often do you or anyone in your shop hunt lionfish per week? (*check most appropriate*)

i. <5

ii. 5-10

iii. 10-15

iv. >15

b. How many do you remove on a typical hunt? (*check most appropriate*)
   i. <5
   ii. 5-10
   iii. 10-15
   iv. >15
c. What becomes of the fish after being caught? (*check all that apply*)
   i. Released
   ii. Discarded
   iii. Used for bait
   iv. Sold to restaurants
   v. Personally consumed
   vi. Other(specify)______________________________________

9. Would you be willing to participate in lionfish tournaments, competitions, or hunts if it were eco-friendly or benefited the Aruban economy? **Y** or **N** (*circle one*)

10. Have you eaten lionfish? **Y** or **N** (*circle one*) ***If NO go to question 12, If YES skip 12***

11. Would you eat lionfish if it were eco-friendly, tasty, or both? (*check one*)
   - ☐ Eco-friendly
   - ☐ Tasty
   - ☐ Both

Figure B-2. *Example of the survey read to Aruban divers.*

SURVEY FOR RESTAURANT OWNERS

Age Category (*circle one*): 0-20 20-40 40-60 >60 Male/Female (*circle one*)

1. How long have you lived in Aruba? (*circle one*)
   a. <5 years
   b. 5-10 years

c. 10-15 years
d. >15 years

2. What brought you here if moving from another location (*circle one*)
   e. Family
   f. Job opportunity
   g. Retirement
   h. Other(specify):____

3. What type of cuisine do you serve at your restaurant? (*check all that apply*)
   - ☐ Seafood **_If check go to question 4, if NO go to question 5_**
   - ☐ Italian
   - ☐ American
   - ☐ Asian
   - ☐ German
   - ☐ Spanish
   - ☐ Other(specify):____

4. Where do you get the seafood you serve? (*check all that apply*)
   - ☐ Local fishermen
   - ☐ Local market
   - ☐ Imported
   - ☐ Self caught
   - ☐ Other(specify):____
5. Are the fish you serve affected by seasonality? **Y** or **N** (*circle one*)

* *I will show an image of a lionfish to those being surveyed to ask the next series of questions.*

6. Have you ever seen this fish? **Y** or **N** (*circle one*) **_If NO, go to question 7_**
   a. Do you know the name of it? **Y** or **N** (*circle one*)
   b. What is it?______________________________________
   c. Where did you see them? (*check all that apply*)
      i. News (online or televised)
      ii. Scientific journal

iii. Personal research/interest
iv. Diving/snorkeling/swimming
v. Fishing
vi. Documentary
vii. Menu/seafood market
viii. Other(specify):____

7. Do you serve lionfish? **Y** or **N** (*circle one*) ***If NO go to question 8***
   a. Where did you get it?____________________________________
   b. When was the first time you served it?______________________
   c. Why did you make that choice? (*briefly explain*)____________________
   ____
   d. How do you prepare it?____
   e. What are the reactions of customers?______________________________
   f. Do you advertise lionfish as a “special” cuisine? **Y** or **N** (*circle one*)
   g. Are people more willing to try it? **Y** or **N** (*circle one*)

8. Would you be willing to serve lionfish if it were eco-friendly and/or benefited the economy of Aruba? **Y** or **N** (*circle one*)

9. Would you be willing to support local fisherman if they were selling it? **Y** or **N** (*circle one*)
   a. Why/why not?____
   ____

10. Would you recommend that other restaurants serve lionfish? **Y** or **N** (*circle one*)

11. Have you been impacted by lionfish? **Y** or **N** (*circle one*) ***If NO go to question 13***
    a. How have you been impacted by lionfish? (*check all that apply*)
    i. Loss of income
    ii. Bad reputation
    iii. Increased income
    iv. Improvements to fishing techniques
    v. Increase capture of fish
    vi. None

vii. Other(specify):____

12. Would you participate in organized lionfish tournaments, competitions or hunts? **Y** or **N** (*circle one*)

Figure B-3. *Example of the survey read to restaurant owners in Aruba.*

SURVEY FOR GOVERNMENT OFFICIALS

Age Category (*circle one*): 20-40 40-60 >60 Male/Female (*circle one*)

1. How long have you lived in Aruba?
   a. <5 years
   b. 5-10 years
   c. 10-15 years
   d. >15 years

2. How long have you held a position in office?
   a. <1 year
   b. 1-2 years
   c. 2-4 years
   d. >4 years

**I will show an image of a lionfish to those being surveyed to ask the next series of questions.*

3. Have you seen this fish? **Y** or **N** (*circle one*)
   a. Do you know the name of it? **Y** or **N** (*circle one*)
   b. What is it? ________________________________

4. Do you consider this fish to be a problem for the island? Why and/or why not? Briefly describe.

5. Do you think this fish should be removed from Aruban waters? **Y** or **N** (*circle one*) **If NO go to question 6**
    a. Who is responsible for removing this fish? Briefly describe.
    b. What do you suggest is the most efficient way to do so? Briefly describe.
    c. Who should finance it? Briefly describe.

6. Are there any regulations currently in place for this fish? **Y** or **N** (*circle one*) **If NO go to 7c**
    a. What are they?
    b. Do you feel that the regulations are sufficient for their intended purposes?
    c. Do you feel that regulations should be implemented? Why or why not.

7. Would you help in (i.e. promote, sponsor, and/or fund) guided lionfish derbies, tournaments, or hunts if it benefited the economy and environment? **Y** or **N** (*circle one*)

8. Do you think lionfish could be used to benefit Aruba? If so, how? If not, why not?

9. If lionfish can benefit Aruba, would you be willing to help promote it or implement regulations that can help? **Y** or **N** (*circle one*)

Figure B-4. *Example of the survey read to government officials in Aruba.*

SURVEY FOR LOCAL ARUBANS

Age Category (*circle one*): 0-20 20-40 40-60 >60 Male/Female (*circle one*)

1. How long have you lived in Aruba? (*circle one*)

   a. <5 years
   b. 5-10 years
   c. 10-15 years
   d. >15 years

13. What brought you here if moving from another location (*circle one*)
    a. Family
    b. Job opportunity
    c. Retirement
    d. Other(specify):_______________________________________

14. Have you participated in any diving, snorkeling, fishing, swimming, or other activities in the ocean here? (*check all that apply*) ***If NO move to question 5***
    - ☐ Diving
    - ☐ Snorkeling
    - ☐ Fishing
    - ☐ Swimming
    - ☐ Other(specify)____________________________________

15. What is your greatest concern when entering the water? (*circle one*)
    a. Currents
    b. Waves

c. Sharks
d. Fish
e. Jellyfish
f. Corals
g. Other(specify):____

16. What type of cuisine have you ordered here? (*check all that apply*)

- ☐ Seafood
- ☐ Italian
- ☐ American
- ☐ Asian
- ☐ German
- ☐ Spanish
- ☐ Other(specify)______________________________________

17. Where have you eaten on the island? (*check all that apply*)

- ☐ Hotel restaurant
- ☐ Local restaurant
- ☐ Local's home
- ☐ Other(specify)______________________________________

18. Do you intend to or normally eat seafood? **Y** or **N** (*circle one*) ***If NO skip to question 8***

a. If you ordered seafood, what did you choose?_____________________
____
____

**I will show an image of a lionfish to those being surveyed to ask the next series of questions.*

19. Have you ever seen this fish before? **Y** or **N** (*circle one*) ***If NO skip to question 9***

If yes, answer the following questions:

a. Do you know the name of it? **Y** or **N** (*circle one*)

b. What is it?____

c. Where have you seen them? (*check all that apply*)

- ☐ News (online or televised)
- ☐ Scientific journal
- ☐ Personal research/interest
- ☐ Diving/Snorkeling/Swimming ***If checked, see d and e***
- ☐ Documentary
- ☐ Menu/seafood market
- ☐ Other(specify)________________________________

d. How many times did you see it in the ocean? (*check most appropriate*)

- ☐ <5
- ☐ 5-10
- ☐ 10-15
- ☐ >15

e. How many did you see? (*check most appropriate)*

- ☐ <5
- ☐ 5-10
- ☐ 10-15
- ☐ >15

20. Has lionfish been served anywhere that you have eaten? **Y** or **N** (*circle one*)

21. Did you try it? **Y** or **N** (*circle one*) ***If NO go to question 11***

a. Were you recommended to try it by your waiter, other clients, or a web search? (*check all that apply*)

i. Waiter

ii. Other clients

iii. Online

iv. Other(specify)________________________________

b. Would you eat it again or recommend it to friends/family? **Y** or **N** (*circle one*)

c. If served in your hometown, would you eat it there also? **Y** or **N** (*circle one*)

22. Would you enjoy eating such a fish? **Y** or **N** (*circle one*)

Lionfish is a good, white tender meat fish with a taste and texture between a snapper and a grouper. It is not restricted on preparation or seasoning, as it is good fried, grilled, steamed, as sushi or seviche, and served whole or filleted.

23. Would you eat lionfish if it were eco-friendly and/or benefited the economy of Aruba? **Y** or **N** (*circle one*)

Figure B-5. *Example of the survey read to local Arubans.*

SURVEY FOR TOURISTS

Age Category (*circle one*): 0-20 20-40 40-60 >60 Male/Female (*circle one*)

1. Where city/state or country are you visiting from?____________________

2. Is this your first time to Aruba? **Y** or **N** (*circle one*) ***If NO move to 2a***
   a. How many times have you been here? (*check most appropriate*)
      - ☐ 0-5
      - ☐ 5-10
      - ☐ 10-15
      - ☐ >15
3. What made you choose Aruba as a destination? (*Circle all that apply*)
   a. Relatives
   b. Personal recommendation
   c. Natural attractions
   d. Cost
   e. Cuisine
   f. Other(specify)____

4. Have you participated in any diving, snorkeling, fishing, swimming, or other activities in the ocean here? (*check all that apply*) ***If NO move to question 5***

- ☐ Diving
- ☐ Snorkeling
- ☐ Fishing
- ☐ Swimming
- ☐ Other(specify)____

5. What is your greatest concern when entering the water? (*circle one*)
   a. Currents
   b. Waves
   c. Sharks
   d. Fish
   e. Jellyfish
   f. Corals
   g. Other(specify):____

6. What type of cuisine have you ordered here? (*check all that apply*)
   - ☐ Seafood
   - ☐ Italian
   - ☐ American
   - ☐ Asian
   - ☐ German
   - ☐ Spanish
   - ☐ Other(specify)____

7. Where have you eaten on the island? (*check all that apply*)
   - ☐ Hotel restaurant
   - ☐ Local restaurant
   - ☐ Local's home
   - ☐ Other(specify)____

8. Do you intend to or normally eat seafood? **Y** or **N** (*circle one*) ***If NO skip to question 8***

a. If you ordered seafood, what did you choose?______________________
____
____

**I will show an image of a lionfish to those being surveyed to ask the next series of questions.*

9. Have you ever seen this fish before? **Y** or **N** (*circle one*) ***If NO skip to question 9***

   If yes, answer the following questions:

   a. Do you know the name of it? **Y** or **N** (*circle one*)
   b. What is it?_______________________________________
   c. Where have you seen them? (*check all that apply*)
      - ☐ News (online or televised)
      - ☐ Scientific journal
      - ☐ Personal research/interest
      - ☐ Diving/Snorkeling/Swimming ***If checked, see d and e***
      - ☐ Documentary
      - ☐ Menu/seafood market
      - ☐ Other(specify)________________________________
   d. How many times did you see it in the ocean? (*check most appropriate*)
      - ☐ <5
      - ☐ 5-10
      - ☐ 10-15
      - ☐ >15
   e. How many did you see? (*check most appropriate)*
      - ☐ <5
      - ☐ 5-10
      - ☐ 10-15
      - ☐ >15

10. Has lionfish been served anywhere that you have eaten? **Y** or **N** (*circle one*)

11. Did you try it? **Y** or **N** (*circle one*) ***If NO go to question 11***

a. Were you recommended to try it by your waiter, other clients, or a web search? (*check all that apply*)
   - ☐ Waiter
   - ☐ Other clients
   - ☐ Online
   - ☐ Other(specify)________________________________

b. Would you eat it again or recommend it to friends/family? **Y** or **N** (*circle one*)

c. If served in your hometown, would you eat it there also? **Y** or **N** (*circle one*)

12. Would you enjoy eating such a fish? **Y** or **N** (*circle one*)

Lionfish is a good, white tender meat fish with a taste and texture between a snapper and a grouper. It is not restricted on preparation or seasoning, as it is good fried, grilled, steamed, as sushi or seviche, and served whole or filleted.

13. Would you eat lionfish if it were eco-friendly? **Y** or **N** (*circle one*)

Figure B-6. *Example of the survey read to tourists in Aruba.*